Wireless, One-Way, Sensor to Base Station Monitoring System for Explosive and Non-Hazardous Environments

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ABSTRACT

The developed technology is a highly power conservative monitoring system consisting of a base station and wireless sensor units. The sensors lay fully unpowered within a dormant state until they receive a trigger energy which consumes no stored power. When activated, the sensor takes a measurement, transmits the data to the base station with a synchronized time stamp, and then returns to its dormant state. The system can be utilized in commercial applications that require long term monitoring of events associated with different types of strain, cryogenic temperatures, ambient temperatures, limit switches, milliamp signals, volt signals and magnetic fields. Though designed to improve the monitoring of high-geared ball and linearly-actuated valves used in propulsion testing to predict valve life span and failure, its use is not limited to valves. It can monitor the operational data of any suitable structure, such as temperature in a particular location in a building, or the strain at a specific point on a bridge.

Keywords: power-conservative, monitoring, sensor, measurement, instrumentation, data, time-stamp, events, strain, temperature, limits, signals, magnetic, predictive

1 BACKGROUND

The ground propulsion test environment at Stennis Space Center (SSC) produces extreme conditions. The explosive combustion of cryogenic fuels into a high heat plume produces some of the highest vibrational environments that can be found. Closely monitoring the facilities in these extreme conditions is necessary to accomplish successful testing and may be critical for maintaining a safe environment. Monitoring all the facilities components would be preferable, but conventional instrumentation required is cost prohibitive. Therefore, resources are distributed wisely based on criticality and practicality. Improving facility monitoring efforts while wisely allocating resources is a continuous endeavor. The

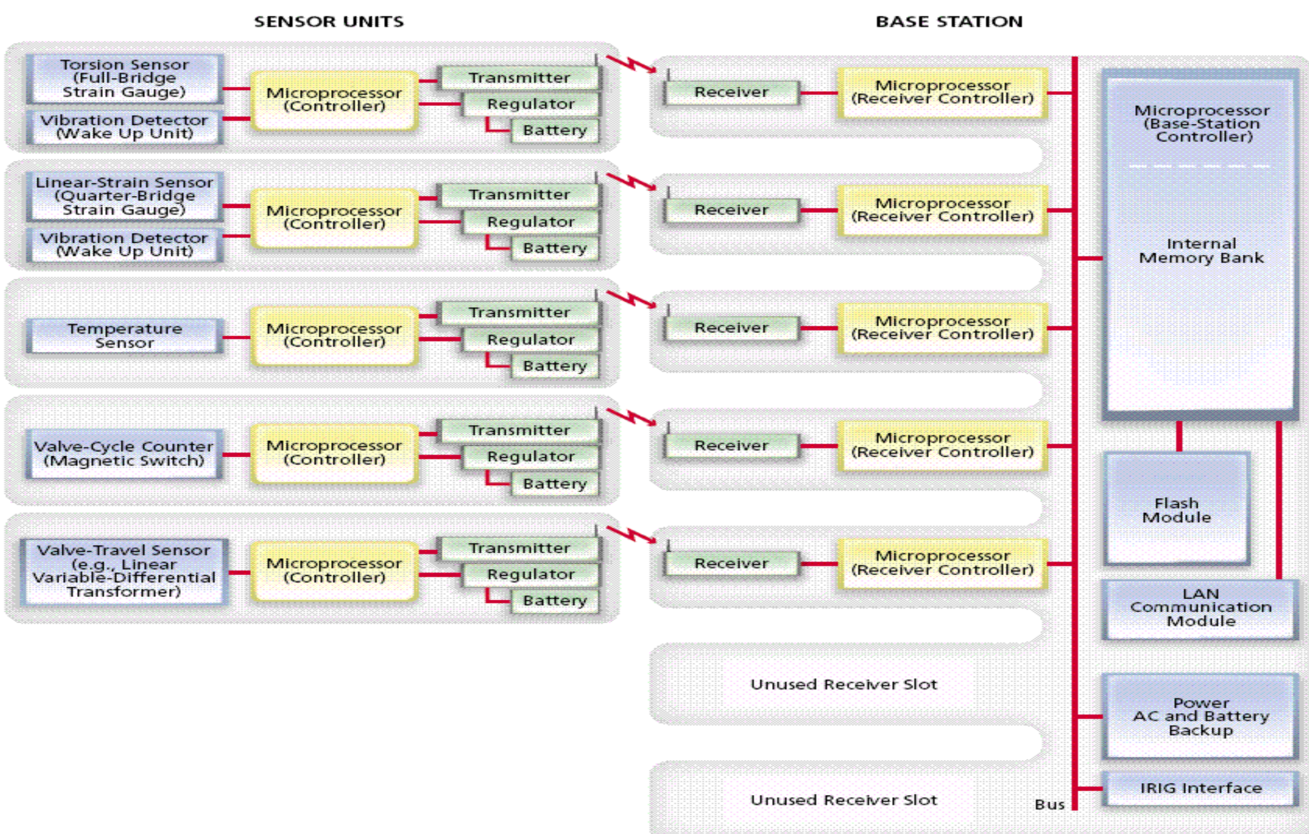

Figure 1: General architecture of the wireless, one-way, sensor to base station monitoring system

developed technology incorporates several innovative technologies into a patented power conservative system.

The wireless, one-way, sensor to base station monitoring system (see Figure 1) was originally developed as a Valve Health Monitoring System (VHMS). Previous propulsion testing incurred unexpected schedule delays and costs due to untimely maintenance, repair or replacement of facility valves. The limited operational data available on these test critical valves make their life expectantcy unpredictable. Life and failure predictions can be greatly improved through added valve instrumentation, but conventional instrumentation methods have been cost prohibitive. For these reasons, the development of a deployable monitoring system was investigated. Applying new integrated electronic technology in the form of smart sensors organized in a smart instrumentation system is a cost effective way of implementing a VHMS. This technology was created as a more practical method of monitoring the large, unique valves used throughout the SSC test facilities. The VHMS is an intelligent sensing system that consists of a base receiver station and multiple wireless sensor units. The system is primarily intended for monitoring valves, but is capable of monitoring all kinds of facility hardware. The system was successfully deployed as a structural monitor on a SSC hydrogen dock to monitor the rusting support pilings that were beginning to compromise the docks integrity. The system allowed safe operating conditions to be conducted daily and it provided real time safe to access indication until repairs could be completed (see Figure 2). The wireless sensor units are attached to the hardware and stay with the hardware for life. This enables tracking of the hardware's operational history through different test programs and applications. It was created for the harsh rocket propulsion environment with solar, thermo, vibrational, and wind energy harvesting capabilities. Energy harvesting has greatly improved the systems applicability by removing its dependency on batteries, eliminating the need for changing out battery packs within the test facilities' explosive environments. It also allows the sensor units to be placed in inaccessible locations or be embedded within structures.

The technology was constructed with data tracking and archiving capabilities beneficial in building a valve knowledge base. The data tracking required were identified as: cryogenic valve cycles, inlet temperature, outlet temperature, valve body temperature, total valve cycles, cryogenic valve cycles, torsional strain, linear bonnet strain, valve preload position. The VHMS was instrumented to log events associated with previously listed collection types, and all the data events are time stamped to allow data synchronization within one millisecond (see Figure 3).

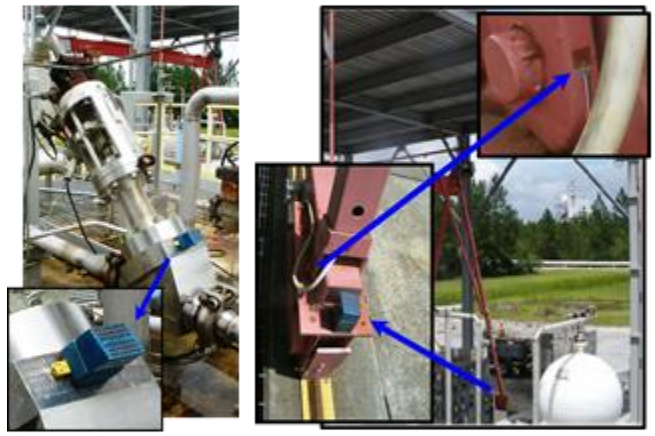

Figure 3: Images of the monitoring system in use on a linear actuated valve and test cell hoist

2 WIRELESS, ONE-WAY, SENSOR TO BASE STATION MONITORING SYSTEM

The monitoring system was primarily constructed as a torsional and linear strain sensor system. The system has proven to be a versatile data tracking system made small enough to be mounted anywhere it is needed. The units are potted in a hydrogen compatible material to meet Class 1 Division 2 specifications. Another sensor unit type, the limit switch sensor unit, was constructed for counting the cycles a valve has under gone while in service. The switch sensor unit uses magnetic position switches for indicating a valve state. Another sensor unit type, the temperature sensor unit, was constructed to monitor the inlet and outlet temperatures utilizing cold junction referenced

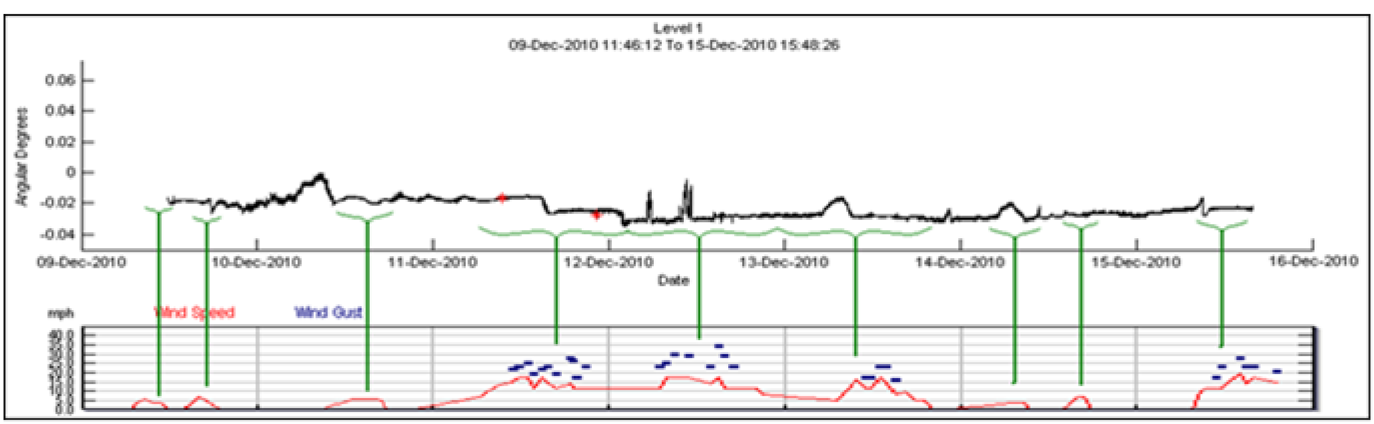

Figure 2: Data collection example from the SSC hydrogen dock structural monitor effort

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thermocouples. A signal sensor unit was designed to unobtrusively interface into the Linear Voltage Differential Transformer signal from most valve servo controllers. A 20 milliamp signal, 10 volt signal and a magnetic sensor capable of denoting a unit's orientation within the earth magnetic fields were also constructed as part of the VHMS.

A primary novelty of the system is it's highly power conservative operation making it maintainable on a large scale and ideal for energy harvesting. A dormancy technology was developed that enables the system's sensor units to go into a fully powered down state. An extremely low powered transistor allows energy collected from external events to power it and be evaluated without using any internal power. Upon an adequate event, the system is reenergized with activation power coming from the event itself. At all other times, energy from the environment is stored.

A special communication protocol was designed for power conservation and time synchronization within a millisecond. If an event occurs an entry into the data log is made in order to identify any possible data corruption, low battery, out of operational conditions or synchronization issues. The base station has an Inter-Range Instrumentation Group (IRIG) time codes decoding module which provides a digital signal to all the base station receiver units. These units synchronize each sensor unit's time to the IRIG time. The sensor units automatically perform internal zero, span, and 80 percent calibrations. A data read event is passed to the base station's main microprocessor which correlates any other applicable data from other sensor unit such as inlet temperature. The refined event log is then stored in a text string on a removable flash memory card as a local data backup and the events broadcasted on an Ethernet network for remote access. The sensor unit can be configured to go into a sleep mode or become dormant to conserve power. In sleep mode, the unit automatically wakes up every 16 seconds and performs an update. It tests for nominal operational conditions and returns to a dormant or sleep mode. If an out of nominal condition or data read event is recognized a data log entry is made to capture the event.

The sensor units are capable of synchronously or asynchronously collecting data. The asynchronous data collection can be triggered by a change in any sensor input, harvested energy, or minute vibration. The sensor units use a highly sensitive internal piezoelectric vibration sensor with an adjustable trigger level. The vibration sensor is capable of detecting an individual walking over 10 feet away and able to detect minute pops, cracks, creaks and clinking parts. A data read event can be configured to collect a single value, averaged value, data bursts, or continues data stream. The data log can be manually collected or an automated system can be implemented for uploading data. The sensor unit must also wake up on an observed data event. The type of sensor unit determines the method used to wake up from power down mode. The switch sensor unit looks for a change in input switch state. The signal sensor unit looks for a change in input signal. The temperature sensor unit logs the change in temperature during its update phase. All the other sensor units use a highly sensitive piezo-eletronic vibration sensor laminated sheet to wake up. A minute vibration from any movement on or near the valve awakens the unit. The laminated piezo-eletronic film vibration sensor needs no excitation voltage and offers a very power conscious wake up circuit and it provides reenergizing power for the dormancy functionality.The transmissions are restricted to low power to avoid introducing noise in pre-existing instrumentation. Anytime wireless communications are implemented in the test facility, security becomes an issue. The units meet Federal Communication Commissions requirements and require no further certifications. The low-power transmissions limit the physical distance the signal can be received, ranging from a 35 to 450 foot radius. The onboard microprocessors have the computing capability for

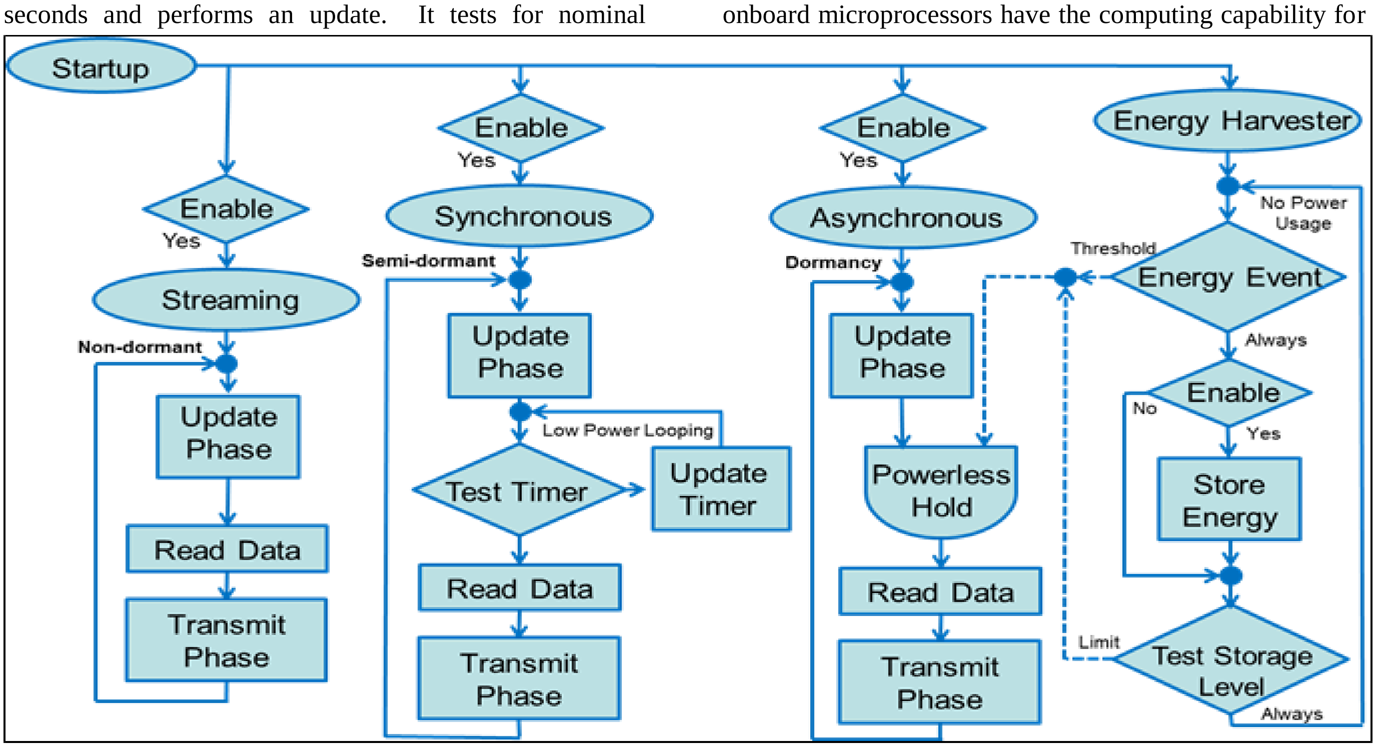

Figure 4: Operational Flow Diagram of the wireless, one-way, sensor to base station monitoring system

performing encryption methods. The limited power transmission also conserves sensor unit power and helps limit cross transmissions between units.

The sensor units have imbedded magnetic switches for maintenance interface. Placing a magnet near the unit awakens it and a light emitting diode flashes a code to indicate low battery levels or other operational errors. Data log transmissions will occur alerting necessary maintenance such as battery pack replacement. Simple operational processes can be implemented for changing the sensor unit battery with no risk of creating an ignition source within a hydrogen environment. The sensor units are restricted to a +/-5 Volts at 250 milliamp level reducing the power level below the hydrogen ignition curve. The base station must be mounted in National Electrical Manufacturers Association (NEMA) class 4 enclosures with a purge (Figure 4). The sensor units are manually accessible from an interface connection under the secondary battery pack. The interface provides RS-232 serial communications and onboard programming capabilities.

The largest power consuming portion of the system is the wireless transmission device. It must be powered down for the majority of operation time. This means a receiver on the sensor unit is not an option. A one way communication protocol must be implemented which makes time synchronization difficult to achieve. The sensor unit and base station receiver unit both have accurate oscillators which can keep time within a quarter of a millisecond for over five weeks. The sensor unit transmits it's time once a day to the base station. It only needs to perform one transmission in order to maintain accurate time synchronization. The base station keeps the previous day's time synchronization if a transmission error occurs or no transmission is made. If such an event occurs an entry into the data log is made in order to identify any data corruption due to time stamping. The monitoring system has 35 days to perform a good data synchronization link-up before any time accuracy is at risk. The base station has an IRIG-B timing module which provides a digital signal to all the base station receiver units. These units synchronize the sensor unit's time to the IRIG time. When a data event occurs, the sensor unit transmits the event and its time according to an internal clock. Redundant transmissions are performed to avoid data transmission errors. The base station receiver unit converts the sensor time to IRIG time. The data event is then passed to the base station's main microprocessor which correlates other applicable data, such as inlet temperature. The refined event log is then stored in a text string on a removable flash memory card and broadcasted on an Ethernet network.

The monitoring system is a feasible solution for helping maintain high-geared ball valves and linear actuated valves within the oropulsion test facilities. The systems' components are manufacturable and feasible for outsourcing. A higher level facility monitoring system with automatic upload capabilities would be able to take advantage of this monitoring system's full potential. In addition, the wireless monitor system requires very little maintenance and is a powerful standalone system that can be readily deployed for all kinds of monitoring needs.

REFERENCES

[1] Jensen, Scott L., Patent US 8,619,933 B2 awarded December 31, 2013, for the Monitoring Method and Apparatus Using Asynchromous, One-Way Transmission from Sensor to Base Station.