A SYNERGISTIC TEST FLIGHT
SMART SENSORS, EQDR AND PCM BACKFILL

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ABSTRACT

This is the story of three projects, which use three different research funding sources, coming together to demonstrate a small, but complete, instrumentation system that advances several technologies. The Onboard Smart Sensor (OSS) project is a Small Business Innovation Research (SBIR) project that incorporates IEEE 1451.4 sensors into an existing Common Airborne Instrumentation System (CAIS) based instrumentation system. These sensors are “smart” in that they can self-identify basic information via a Transducer Electronic Data Sheet (TEDS). The Enhanced Query Data Recorder (EQDR) is being developed under the T&E Science & Technology Spectrum Efficient Technology (S&T SET) portfolio. This recorder is based on the integrated Network Enhanced Telemetry (iNET) specifications. One of the objectives of iNET is to be able to query a recorder in real-time and transfer the request across a network telemetry link. The third project provides Pulse Code Modulation (PCM) backfill to compensate for dropouts.

One of the envisioned applications enabled by the iNET architecture is the ability to provide PCM displays in the control room that do not have dropouts. This is called PCM Backfill. The basic scenario is that PCM is both transmitted (as it traditionally has been via serial streaming telemetry (SST)) and recorded onboard. When dropouts occur, a request over the telemetry network is made to the recorder (the EQDR in this case) and the dropped portions of the PCM stream are sent over the telemetry network to backfill the ground display. By adding a PCM-to-Ethernet/iNET bridge, the OSS and legacy instrumentation system can provide data to both the

standard PCM and to the EQDR. Combined, this mini-system demonstrates a vision of having intelligence and networking ability across the entire instrumentation system – from sensor to display.

KEY WORDS

Smart Sensors, IEEE 1451.4, iNET, EQDR, PCM Backfill, Telemetry Network System (TmNS)

INTRODUCTION

There has been a vision of an instrumentation system that includes intelligent devices at every level [1]. With the advent of network backbones on the vehicle, as well as, a telemetry network, this vision is becoming reality. This network architecture allows every device to be communicated with directly. If we include intelligence at the sensor level, this implements intelligent devices from sensor to display. On a very small level, the test flight described here demonstrates such a system.

As illustrated in Figure 1, the system under test consists of several components. The smart sensor system (from NVE Corp.) interacts with a legacy CAIS Data Acquisition Unit (DAU) (from Teletronics Technology Corp.) The DAU then outputs two PCM streams: one is telemetered via traditional serial streaming telemetry, the second is sent to a PCM to Ethernet bridge (a Compact Data Manager (CDM) from L3 Communications). The PCM is converted into an integrated Network Enhanced Telemetry (iNET) compatible package which is sent to, and recorded on, an Enhanced Query Data Recorder (EQDR) (provided by Leidos Corp.). During the flight test, dropouts to the PCM stream are expected (or will be created). This causes the Mission Control System (MCS) Telemetry Processor to request backfill data via the telemetry link to the EQDR. The EQDR then transmits the requested data back to the MCS and a pristine (without dropouts) PCM stream is presented to the user in the control room.

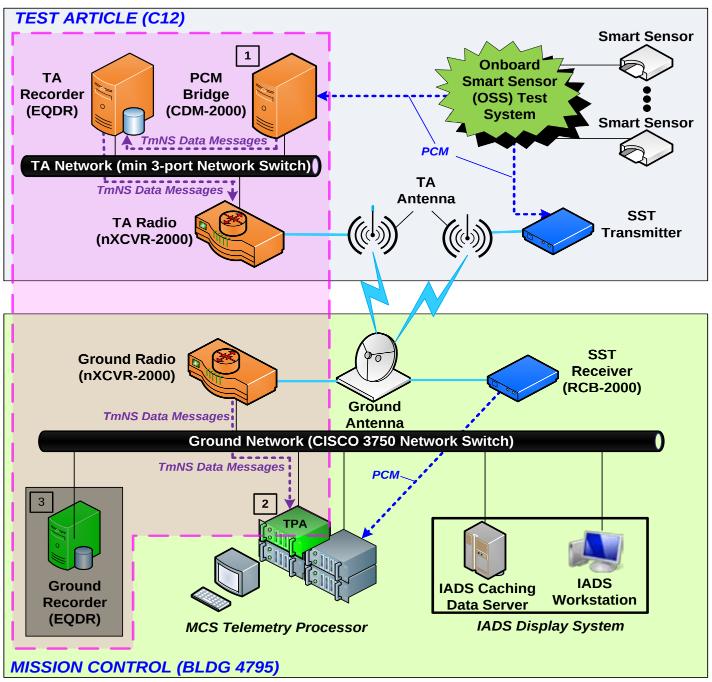

Figure 1 – System Block Diagram

ONBOARD SMART SENSORS (OSS)

The Onboard Smart Sensor (OSS) system has been developed under the Small Business Innovation Research (SBIR) program. The objective has been to develop DAU equivalents that implement the architecture of the IEEE 1451.4 smart sensor standard [2]. The fundamental architecture of the IEEE 1451 standards includes a Network Capable Application Processor (NCAP) and a Smart Transducer Interface Module (STIM). The NCAP is intended to interface between the STIM and some bus or network. The idea is that an NCAP specific to one bus protocol can be substituted for a different NCAP for a different protocol without having to modify the STIM. The STIM provides the smart sensor interface. As illustrated in Figure 2, the OSS implementation uses a Universal STIM (USTIM) that includes 8 sensor ports. The OSS Multi-NCAP is also designed to support multiple USTIMs.

The IEEE 1451.4 standard is referred to as a "mixed-mode" interface. It provides to communication methods to the sensor: a digital interface that communicates with the sensors memory and an analog interface that transmits the standard analog signal from a transducer. In its simplest form on a two wire sensor, the digital and analog modes are accomplished by changing the polarity. A fully compliant IEEE 1451.4 sensor includes memory designed into the sensor. But there is a requirement to be able to use legacy "dumb" sensors and it is possible to convert these sensors into smart sensors by adding inline memory. The OSS adds memory this way via a Sensor Identification Transducer Electronic Data Sheet (SITEDS). In either case, the memory allows sensors to be self-identifying. That is, they can be queried to return full spec sheet information such as serial number, model number, calibration data, or any other information the user or manufacturer wants to store in it.

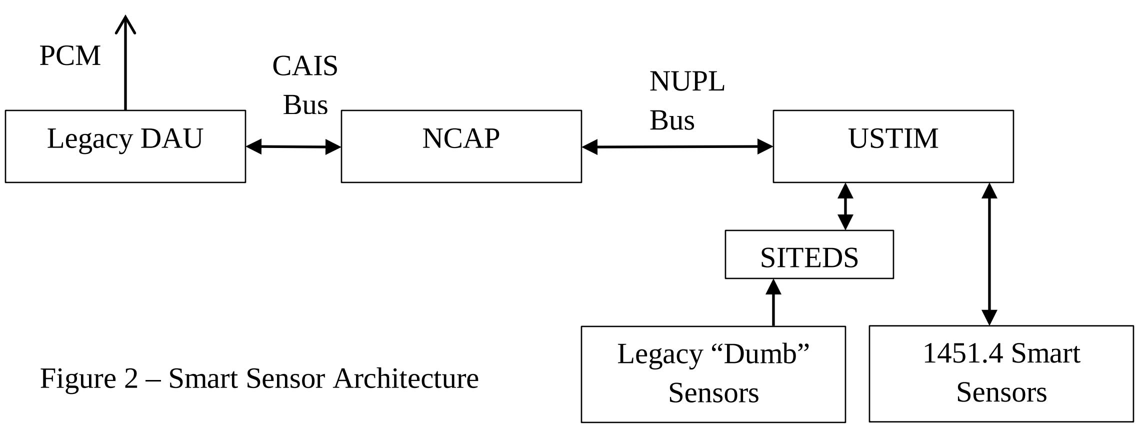

Figure 2 – Smart Sensor Architecture

ENHANCED QUERY DATA RECORDER (EQDR)

The Enhanced Query Data Recorder (EQDR) was developed under the Test Resource Management Center's (TRMC) Spectrum Efficient Technologies (SET) S&T program. The EQDR is a network flight recorder built around the iNET standards and which is intended to meet the future needs of the networked telemetry environment. The EQDR is designed to support the "fetch" of recorded test data during a test without interruption to the ongoing recording of data from the test article vehicle network.

The key benefits of the network data recorder as implemented in EQDR are increased flexibility and efficiency of test in an environment with increasing demands on spectrum available for telemetered data. EQDR enables retrieval of individual recorded parameters on an as-needed basis. Having the flexibility to send data only when it is required rather than throughout the duration of the test significantly increases the efficiency with which limited spectrum resources are used. EQDR enables parametric-level data retrieval, based not only on time interval and data source, but also on the content of the recorded data messages. EQDR enables selective, efficient retrieval of individual parameters using indexes derived from the actual values of recorded data.

Within the context of the flight test demonstration described in this paper and as illustrated in Figure 1, the onboard smart sensors combined with the CDM act as a data source of iNET TmNS data messages for the EQDR onboard the C-12 aircraft. In this instance, the payload of the TmNS data message is a traditional PCM minor frame that has been generated by the OSS. The CDM wraps the PCM minor frame into a TmNS data message and sends it out onto the Ethernet network as multicast data. The aircraft EQDR has been configured to be a data sink for the TmNS messages created by the OSS-CDM system. There is also an instance of EQDR running on the ground. It records the TmNS data messages that have been received by the ground network.

Upon receiving the TmNS messages containing the embedded OSS PCM frames, the aircraft EQDR processes the TmNS data messages by breaking them apart and analyzing their content before recording them. In this test, the TmNS message payload is a PCM frame, and the EQDR further breaks down the contents of the minor frame. The system generates metadata about the individual parameters within the minor frame contained in the TmNS packet payload, and the metadata is stored within the EQDR along with the parameters to enable rapid, selective retrieval of individual parameters in the future.

The EQDR can be controlled from the ground. Recording can be started or stopped as defined in the iNET standards though an SNMP request, which in the case of the system described in the paper, is issued by the MCS telemetry processor. Similarly, the EQDR will respond to SNMP playback requests issued by the MCS telemetry processor. These capabilities are demonstrated in Scenarios 3 and 4, which are described in more detail in the final section of this paper, during the flight test.

One of the primary use cases for the EQDR is that of PCM backfill, which is described in more detail in the following section. In this instance, the EQDR responds to playback requests initiated by the MCS telemetry processor, which is responsible for the mechanics of detecting losses and integrating retransmitted parameters from the EQDR into a pristine telemetry stream on the ground. PCM back is demonstrated in Scenario 5 of the flight test.

The EQDR can also support open-ended requests issued from ground, in which case it essentially acts as an iNET latency time critical (LTC) to reliability critical (RC) relay node. This is demonstrated in Scenario 6 of the flight test demonstration.

As previously mentioned, when the EQDR receives TmNS message data, it analyzes individual parameters within the TmNS payload and generates metadata about the parameters that are being recorded. This metadata enables the ground station to issue "enhanced queries" of recorded data based on specific attributes of the data itself, a capability which is demonstrated in Scenario 8 of the flight test. The capability is an extension of the iNET standards, which do not require the network recorder to generate metadata or to support retransmission of individual parameters based on the characteristics or values of the recorded data. In Scenario 8, an "enhanced query" of the EQDR is performed using a web client to the EQDR Configuration Tool. In this scenario, the ground operator issues an ad hoc request of the envelope of values of a specific parameter contained within the PCM frame, over a specified time interval. This envelope is displayed on the ground web client. A follow-up query of all measurements within a subset of the initial time interval is then issued, in which all values and not just the envelope representing maximum and minimum are retransmitted to ground over the RF link.

PCM BACKFILL

A test flight is a series of test points. Test points are not always flown correctly first time they are tried. Further, test points are sometimes sequentially dependent with increasing risk. Each test point is thus validated before moving on to the next test point. The purpose of data monitoring in the control room is to insure the integrity of the data recorded and to make sure the test was conducted in a way that maximizes the usefulness of the data collected. By providing error free data in the control room, engineers are able to engage in more extensive data analysis in real-time, thus allowing for critical decisions to be made rapidly. This can allow implementing more test points during a test and avoiding costly and time consuming re-testing.

In a typical test scenario, engineers monitor data in a control room for several purposes, chief among them are safety of flight and test efficiency. PCM Backfill may play a role in both of these purposes but should be the most beneficial for test efficiency. The data retrieval process takes some finite amount of time so PCM Backfill may or may not provide additional information in the split-second timing needed to make safety of flight decisions. However for test efficiency, PCM Backfill might recover data so that a test point with dropouts does not need to be repeated. This allows the project to move on to the next test point quickly thus saving money for the project.

The MCS system performs a serial to parallel conversion of the SST PCM data. The PCM Backfill module receives the parallel PCM data and performs software frame synchronization on the PCM stream. This creates a virtual flow of PCM data frames. When the PCM Backfill module detects a PCM dropout, any subsequently received PCM frames are stored in a first-in-first-out (FIFO) queue for later processing. Once the dropout ends, PCM data frames in the form of TmNS data messages are requested from the test article EQDR. Theses PCM frames are inserted into the virtual flow of PCM data frames to replace the PCM frames lost in the dropout. The completed flow of PCM data frames is output as iNET TmNS data messages, as well as, processed with the standard MCS modules for software decommutation and EU conversion used for standard SST PCM data streams. This pristine data as well as the standard, noisy SST PCM stream are then sent from the MCS to the Symvionics Interactive Analysis and Display System (IADS) to be time aligned and displayed.

RACK MOUNTED SYSTEM

As shown in Figure 3, the OSS hardware and sensors are installed on a shelf mounted in a rack which can be installed on the test vehicle. The rack is about four feet tall and the OSS portion, including the EQDR and sensors takes up less than a foot in the center of the rack. (The rest of the rack contains iNET and other system hardware.)

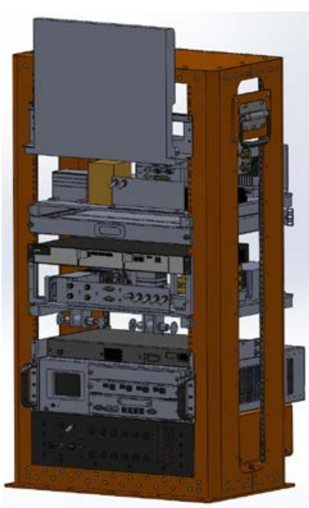

Figure 3 – Smart Sensor Rack

In order to test the smart sensor components a set of sensors are included in the OSS shelf. These include accelerometers, pressure sensors, load cells, and Resistance Temperature Detectors (RTDs) (temperature probes). The test concept is to compare sensors between the different modes: legacy sensors, IEEE 1451.4 compliant sensors, and legacy sensors with SITEDS. Like sensors are mounted near each other. Ideally, there would have been a sensor of each measurement type for each of the 3 modes. However, this was not possible due to availability of sensors and ports.

FLIGHT TEST DEMONSTRATION

The flight test itself consists of a series of test scenarios. Individually they aren't very exciting, but the sequential buildup leads to a complete test of the systems and the PCM Backfill application.

Scenario 1: *Characterize Range for SST and Telemetry Network*. The flight demo is sponsored by and supports the iNET program. This scenario aids in characterizing the iNET transceivers. But it also allows an understanding of the limits of the test equipment and an understanding of what kinds of dropouts can be expected.

Scenario 2: *Verify Data Acquisition System (DAS) and OSS Operational*. This gets things started by making sure the basic system is working and that we are receiving data from the vehicle and displaying it on the ground.

Scenario 3: *Control EQDR From the Ground*. Another application of the network telemetry link is the ability to communicate directly with a device on the plane. This scenario demonstrates that the EQDR can be thus controlled.

Scenario 4: *Query EQDR From the Ground*. This demonstrates further interaction with the EQDR and verifies the fundamental functionality of the EQDR needed to support PCM Backfill.

Scenario 5: *Demonstrate PCM Backfill.* This demonstrates the full functionality of PCM Backfill.

Scenario 6: *Packetized PCM from A/C EQDR Across RF Network*. This scenario compares real time transmission of PCM from the A/C EQDR. That is, the EQDR is recording and retransmitting the PCM from the CDM at the same time across TCP in iNET packets. This is an open-ended RC request issued to the EQDR from MCS_tmnsrecutil tool on ground.

Scenario 7: *Packetized PCM from CDM Across RF Network*. This compares PCM as sent by the CDM (using UDP multicast to send PCM in iNET messages over the TM Network) to the SST PCM stream.

Scenario 8: *Test Enhance Query on EQDR*. Using the EQDR Configuration Tool and associated web server, the ground operator will perform an "envelope query" of specific measurements that have been recorded on the A/C EQDR over a specific time interval.

CONCLUSION

Through serendipitous events and coordination between different people working towards the same goals, a synergistic opportunity arose. A flight demonstration that combines development efforts across multiple funding sources – smart sensors via SBIR, EQDR via T&E S&T and telemetry networks via CTEIP iNET – has been implemented. The test system represents a mini-version of a long term vision of an instrumentation system with intelligence at every level and in every device; an intelligent instrumentation system from sensor to display. We know this is possible; it's just a question of doing it.

REFERENCES

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