Overview of the Smart Network Element Architecture and Recent Innovations

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Abstract

In industrial environments, system operators rely on the availability and accuracy of sensors to monitor processes and detect failures of components and/or processes. The sensors must be networked in such a way that their data is reported to a central human interface, where operators are tasked with making real-time decisions based on the state of the sensors and the components that are being monitored. Incorporating health management functions at this central location aids the operator by automating the decision-making process to suggest, and sometimes perform, the action required by current operating conditions. Integrated Systems Health Management (ISHM) aims to incorporate data from many sources, including real-time and historical data and user input, and extract information and knowledge from that data to diagnose failures and predict future failures of the system. By distributing health management processing to lower levels of the architecture, there is less bandwidth required for ISHM, enhanced data fusion, make systems and processes more robust, and improved resolution for the detection and isolation of failures in a system, subsystem, component, or process. The Smart Network Element (SNE) has been developed at NASA Kennedy Space Center to perform intelligent functions at sensors and actuators' level in support of ISHM.

I. INTRODUCTION

The SNE has been designed to perform low-level ISHM functions and algorithms using a modular architecture that can be tailored to suit the communication, power, and analog interface requirements of any application. The SNE consists of three functional layers: 1) analog signal conditioning and conversion, 2) power and communication, and 3) digital signal processing and intelligent algorithms. ****We'll make reference to a figure here**** Each layer is implemented on a separate printed circuit board with standardized interfaces so SNE modules can be assembled or built to meet application-specific requirements.

II. ANALOG SIGNAL CONDITIONING AND CONVERSION LAYER

The analog signal conditioning and conversion layer provides the excitation voltages required by transducers and the circuitry that converts the transducer's analog signal into digital data. Up to eight transducers can interface with the analog module, and there are redundant paths for the multiplexing, amplification, and analog to digital conversion of the signals. The multiplexers make available differential analog signals from four transducers, the excitation voltages for the transducers, and on-board temperature sensors for compensation. The differential signal is passed through an instrumentation amplifier with high-precision/low-temperature-drift resistors that can be exchanged to modify the gain, and the amplified signal is converted to a digital number using analog to digital converters (ADCs). Multiple-channel ADCs allow for the output of the instrumentation amp from one redundant path to be measured by an ADC on another path. If a failure is detected on one of the paths, the alternate conversion path may be employed so that the SNE can continue taking measurements until a repair can be performed. This configuration differs from the traditional total independent redundant path for signal and increases reliability of the system by providing redundancy at the component level *(Perhaps an ADAS paper can be referenced here, Jose, do you have something we can reference?).*

III. POWER AND COMMUNICATION LAYER

The power and communication layer has the hardware and software that provide the SNE with power and network connectivity.

A. Power

The SNE's power circuitry has the capability to convert power from different DC sources. Besides being powered by a range of typical DC supplies, the SNE can receive power over the spare pair of pins on standard Cat-5 (Ethernet) cable. A Power over Ethernet (PoE) controller on the SNE negotiates its power requirements with a network device that supplies power per IEEE 802.3af. The SNE has filtering and isolation to protect its electronics and the supply. The power is further regulated into the voltages required by the SNE's analog and digital layers. The modularity approach of the SNE allows for many different variations of power modes, depending on the specific application's requirements.

B. Communication

The power and communication layer is equipped with a C8051 microcontroller to handle communication and built-in self-test tasks. Using the C8051, the SNE can interact with higher levels of the ISHM architecture through several different means. The simplest way the SNE communicates is through a serial interface. The SNE can be programmed to send and receive messages using a standard RS-232, RS-485, Ethernet, wireless interface, or more sophisticated communication standards. For example, an existing implementations of the SNE employees an Ethernet controller that enables the SNE to use TCP/IP or UDP/IP protocols in unicast, multicast, or broadcast configuration. By interfacing with commercial-off-the-shelf (COTS) products that provide embedded systems with network connectivity, the SNE's functionality can be made available on most standard buses, such as ControlNet, Profibus, DeviceNet, CANopen, Modbus or Ethernet/IndustrialProtocol. The COTS products allow ISHM to take advantage of the SNE's intelligent functions on a wide array of networks. Several communication modes have been implemented and demonstrated by KSC including Ethernet and ControlNet implementations.

In addition to the flexibility of the SNE to operate on different types of networks, applications have been developed to make the SNE plug-and-play and to synchronize its local time with the network time. The microcontroller that handles the SNE's communication functions may also be programmed as a Network Capable Application Processor (NCAP), according to IEEE 1451.1. The NCAP provides a layer of abstraction for the transducers associated with the SNE, and allows other IEEE 1451.1-compliant devices to get information about the SNE's configuration through Transducer Electronic Data Sheets (TEDS). The TEDS provide the information required for plug-and-play operation of the SNE on the network, and provide other devices with the information required to receive health data from the SNE using an extension of the TEDS, called Health Electronic Data Sheets (HEDS). KSC has implemented and demonstrated IEEE 1451.1 plug and play capability in the SNE.

The SNE may also be programmed with a software implementation of IEEE 1588 Precision Time Protocol to synchronize the SNE's local time with the network's grandmaster clock. The SNE has an on-board Real Time Clock (RTC) that drifts approximately 4 seconds per year to retain the time if no IEEE 1588 grandmaster clock is available. Time synchronization allows the SNE to time-tag the data it is sampling for reconstruction at higher levels of the ISHM architecture.

IV. DIGITAL SIGNAL PROCESSING AND INTELLIGENT ALGORITHMS LAYER

The digital signal processing and intelligent algorithms layer consists of a digital signal processor (DSP) and the communication interfaces required for the DSP to acquire data from the ADCs on the analog layer and communicate processed data, information and knowledge to the power and communication layer so that it can be shared on the network.

A. Digital Signal Processing Techniques

The existing implementation of the SNE can receive up to eight analog inputs from transducers, and each input can be sampled at a rate of 40 KSamples/sec. The high sampling rate allows the floating-point DSP to perform digital filtering and Fast Fourier Transforms (FFT) of the data for frequency analysis. The digital filters and FFT can be developed and verified in MATLAB©'s Simulink environment. Then, C code that is compatible with the DSP can be generated using MATLAB©'s Embedded Code Generator tool. Using MATLAB© tools to create functions which can be called directly by the DSP's C code streamlines the process of filter development and prevents typographical errors in the generation of embedded code.

B. Intelligent Algorithms

Two sets of intelligent algorithms are being developed to support the SNE. The first set of algorithms is intended to monitor, assess and predict the health of the SNE and its components. The second set of intelligent algorithms is intended to monitor, assess, and predict the health of the measurement being provided and ultimately the health of the process being monitored.

The SNE's intelligence is derived from software algorithms that monitor, diagnose and predict failures of the data, as well as a combination of hardware and software that allow the SNE to detect and isolate failures of its own electronic components.

Software algorithms can be developed for the SNE based on its application, and may include threshold detection, rate-of-change detection, statistical analysis, state detection, comparison with physical models, and predictions about remaining useful life based on trending. Because its analog interface can accommodate multiple sensors, the SNE can verify a process by comparing the data from related transducers to physical models. For example, the fusion of data from a pressure and temperature transducer in a gas line would allow the SNE to distinguish between an overpressure condition and a failed pressure transducer.

Other software algorithms are generic and are not dependent on the environment or process that the SNE is monitoring. For example, an algorithm has been developed that takes advantage of the eight analog inputs available to the SNE. If each of the analog input signals is from a redundant transducer, a proprietary algorithm allows the SNE to distinguish healthy transducers from failing ones and produces a single output that is based on the healthy measurements *(we should reference here a MSA paper).* If the transducers use different technologies to perform the conversion of the physical phenomena to an electrical signal, they will tend to drift differently over time (they will be statistically independent). In that case, the single output from the multi-sensor array will be more reliable than any single measurement, and the calibration cycle of the SNE can be extended. Initial modeling based on the drift of a typical sensor indicates a lengthening of at least three times the typical the calibration cycle (we should reference here a MSA paper). ****Need to insert figure****

The SNE's hardware in each functional layer has been designed in such a way that hard failures and out of tolerance measurements can be detected and isolated by the SNE. Fault tree analysis of the components has been performed using TEAMS Designer software, and built-in self-tests have been written for the SNE in C code that are based on the analyses.

The analog signal conditioning and conversion layer has redundant multiplexers, instrumentation amplifiers, voltage references and multichannel ADCs that are configured to verify the reading among the different ADCs. The multiplexers also allow the ADCs to monitor the excitation voltage for the analog inputs and an on-board temperature IC for thermal compensation. A failure of any single component in the signal conditioning path can be identified by the SNE using the built-in self-tests. The analog signal conditioning and conversion layer also uses precision components to ensure the accuracy of the measurements being taken by the analog signal conditioning and conversion layer. The precision components include resistors for voltage bridges and capacitors for frequency and oscillator drift. The precision components allow for self-calibration of the SNE and make it possible to give a real-time measurement tolerance. When the tolerance goes out of range for a particular application, the SNE can notify the network that it is ready for calibration. In this way, calibration can be performed only when it is necessary rather than at generic, manufacturer-defined or field-estimated intervals.

The power and communication layer is equipped with hardware watchdog timers to monitor the internal serial port interfaces between the integrated circuit chips of the SNE. If there is no activity on the interface, the SNE can reset a chip to attempt to restore communication functions. A failure to re-establish communication with the chip will result in a failure diagnosis. The power and communication layer can be outfitted with precision capacitors that allow the SNE to detect drift in the oscillators that control the operation of the on-board real-time clock. In addition, the power and communication layer has software routines that read and write to the serial ports and memory interfaces to verify proper operation of the hardware. If a failure is detected, the SNE records the time and date of the failure in non-volatile memory for future recovery.

V. BENEFITS OF THE SNE TO ISHM

The SNE flexible architecture and modularity allows nearly any kind of industrial monitoring network to reap the benefits of distributed ISHM. The SNE's on-board diagnostic capabilities, paired with its self-calibration and notification features in a small package (3.5cm x 10cm x 3.5cm) make it ideal for replacing or augmenting traditional data acquisition systems that do not offer the same scope of intelligent functions and algorithms. ****Include a picture of the SNE here****

The SNE gives operators of industrial systems a real-time awareness of the health of processes and components, and provides higher-level ISHM with more resolution to determine the root cause of a failure in a timely manner. Although traditional transducers and data acquisition systems may meet the required availability and reliability for many systems, the SNE offers the redundancy and autonomous diagnostic capabilities that are important to safety critical applications and ISHM-enabled systems that are looking to take advantage of distributed processing power at the sensor level.

VI. ACKNOWLEDGMENT

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REFERENCES

[1] Institute of Electrical and Electronics Engineers, Inc., "IEEE 1451.1 Standard for Smart Transducer Interface for Sensors and Actuators – Network Capable Application Processor (NCAP) Information Model," Mixed-Mode Communication Working Group of the Technical Committee on Sensor Technology TC-9 of the IEEE Instrumentation and Measurement Society, June 1999.

[2] Institute of Electrical and Electronics Engineers, Inc., "IEEE 1451.4/3.0 Standard for Smart Transducer Interface for Sensors and Actuators – Mixed-Mode Communication Protocols and Transducer Electronic Data Sheets (TEDS) Formats," Mixed-Mode Communication Working Group of the Technical Committee on Sensor Technology TC-9 of the IEEE Instrumentation and Measurement Society, New York: April 2004..

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14. ABSTRACT

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