Smart Sensors’ Role in Integrated System Health Management

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Payload deployment in space has become very competitive

- Europe, Japan and China have driven down the cost-per-pound of payload to almost a third from 1990 to 2000
- Cost has leveled in recent years to around $12,000/lb*

One of NASA’s goals is to reduce this cost by a factor of 10 or more through new technologies development

Integrated System Health Management (ISHM) is one of the new technologies that will help lower costs

- by reducing operating, processing and maintenance costs in flight vehicles and ground support systems

ISHM - Concept

• ISHM is an integrated health monitoring system that automatically and autonomously acquires information from sensors and actuators, and processes that information using embedded knowledge.

• ISHM establishes the health of the system based on the combination of the new acquired information and its prior knowledge.

• Ultimately, ISHM shall provide failure prediction and remediation before actual failures occurs, preventing its costly consequences.

• High-quality data is a key component of ISHM. Data from sensors and their associated data acquisition systems constitute the foundation of ISHM.
Role of Smart Sensors in ISHM

- Provide good data (assess and qualify the validity of the data)
- Provide processed data (data conversion and compensation)
- Provide sensor health status (degradation and failure detection)
- Provide embedded self-healing capabilities (self-calibration and self-reconfiguration)
- Provide sensors networking capability (wired and/or wireless)
- Provide higher reliability and longer calibration cycles
- Provide automation and autonomy, reducing human intervention (reduced maintainability costs)
Smart Sensor - Characteristics

- Self-identification (Configuration Control)

- Embedded intelligence
  - Data digitization and conversion
  - Time stamping and data synchronization
  - Complex signal processing (trending, averaging, etc)
  - Data storage

- Self-health assessment (Data Validity and Availability)
  - Auto-calibration capability
  - Self-reconfiguration capability

- Health Management capability
  - Proposed Health Electronic Data Sheets (HEDS) approach
  
  "health parameters are calculated, monitored and stored in the Smart Sensors to aid in the determination of the sensor’s health"
Smart Sensor - Benefits

• **Assure Data Validity**
  - Measurement “self-health” capability
    - Embedded calibration capability
    - Embedded failure detection and correction capabilities

• **Assure Data Availability**
  - Networked sensor system
    - Provide alternate path to measurement
  - Embedded data storage capability
  - Embedded self-reconfiguration capability

• **Increase Reliability**
  - Reduced calibration cycles
  - Self-reconfiguration capability

• **Information versus data**
  - Data trending, bandwidth reduction, etc
• Smart Sensors, arranged in network configuration, fully provides the enhanced benefits described here

• Communication is now expanded beyond sensor-to-system. Smart Sensors can not only send/receive data from the system but also from associated Smart Sensors in the network

• Sensor’s data, configuration, health, and process status information can be easily exchanged between sensors and between sensors and system

• System becomes more tolerant to communication failures. Network configuration supports alternate communication paths when primary path fails

• Smart sensors networks can be implemented as wired network configurations (Ethernet, RS485, optical), wireless network configurations, or a combination
Smart Sensor - KSC Architecture

Overall System Architecture

Sub System Architecture

Process-specific Intelligent Vehicle Knowledge Entity

Intelligent Sensor Agent

Sensor Suite
Smart Sensor - KSC Architecture

Sensor Suite Architecture

- Communication Layer
  - Intelligent Sensor Agent
  - Data Acquisition
  - Signal Conditioning
  - Sensor(s)

- Calibration System
  - Communication Layer
    - Intelligent Sensor Agent
    - Data Acquisition
    - Signal Conditioning
    - Sensor(s)

Sensor Suite Architecture

- Communication Layer
  - Intelligent Sensor Agent
  - Data Acquisition
  - Signal Conditioning
  - Sensor(s)

- Calibration & Health System
  - Sensor Excitation
  - Signal Amplification (gain, offset)
  - Signal Filtering
  - Single Sensor
  - Multi Sensor Array (MSA)
  - Multidiscipline Sensor Array

- Autonomous calibration
- Sensor/Electronic health
- Degradation detection
- Self-healing capability

- Standardized communication protocol (i.e. TCP over Ethernet)

Embedded Knowledge:
- Provides accurate and reliable data
- Conducts Sensor Suite health checks
- Communicates with other sensor suites to validate data and health of the sensor(s)
- Contains sensor identification and characterization parameters
- Contains parameters to perform sensor validation and measurement interpretation
- Provides sensor data synchronization
Smart Sensor - KSC Prototype

 Prototype stacking concept

Eight element Pressure Sensor Array analog module

SSA/Embedded Intelligence module
Smart Sensor - KSC Predecessors

Smart Sensing

- Multi-Sensor Array Pressure Transducer
- Valve Health Monitor (Current Signature Sensor)
- Sensor Assembly
- Electronics
- H2/O2 MEMS Sensor
- Cabin Pressure Monitoring System
- 3-D Venturi Hurricane Wind Sensor
Multi-Sensor Array (MSA) Transducer

MSA is a fault-tolerant transducer architecture designed to increase at least 3 times present calibration cycle times and to increase measurement reliability.

**Approach**

Array of MEMS sensors and KSC developed software algorithms. Embedded electronics provides autonomous self-health checks.

**Status**

- Reliability studies were completed on 8-pressure sensors array
- KSC-developed algorithms were developed and tested
- Sensor failure simulation was performed to validate software algorithms
- Ruggedized prototype (shown above) was developed and tested
- Patent was granted. Commercialization license was issued to TABER industries
Mini Smart Leak Detector Sensor

- Joint effort between GRC, KSC, MSFC, and MAKEL Engineering

- MEMS type hydrogen/oxygen/pressure/temperature sensor with embedded electronics and processing algorithms

- KSC provides technical expertise to transition design into final product. KSC is also performing functional testing, environmental testing and materials compatibility analysis.

- KSC is presently developing a Wireless hydrogen/oxygen sensor Network (wireless sensor prototype under test)

Photos provided by Dr. Gary Hunter (GRC)
Valve Health Monitor (Current Signature)

Development of a non-invasive sensor, with embedded process-knowledge capability to detect valve’s degradation or failure and ultimately predict failure before it happens (failure trending and prediction)

- Current signature sensor prototype (sensor assembly, analog, digital and power modules) designed, fabricated, and tested
- Smart software algorithms to detect failures and/or degradation under different external conditions developed and tested
- Patent pending. Commercial licensing of this technology has been granted to Schaffer
Advanced Data Acquisition System (ADAS)

Data Acquisition System development that autonomously performs internal health checks and self-healing operations upon failure detection (self-calibration, self-reconfiguration capabilities), and allows for greater measurement reliability with minimum number of component redundancy. Additionally, size, weight and power requirements are minimized.

- Architecture was defined and baselined
- Prototypes were designed and fabricated
- System was tested at laboratory environment
- Embedded software was developed and tested
- 4-channel generic system was demonstrated (shown above)
- U.S. patent # 6,462,684 was granted to KSC
- Commercialization licensing rights were issued to Circuit Avenue Netrepreneurs, LLC
Wireless Sensor Network (SensorNet)

Development of embedded wireless data link capability in Smart Sensors Architecture creates a robust sensor network design (capable of autonomous or “user-demand” reconfiguration)
Development provides networked sensors with embedded process-specific intelligence.

- Generic 433MHz and 918 MHz RF Transceiver and Power Management Module, Sensor Interface Module and Memory Module have been designed, fabricated and tested.
- Smart software algorithms to overcome RF path problems (communication drop out) have been designed and tested. Smart power management algorithms to optimize battery life have been designed and tested.
- Limited process-specific embedded knowledge in sensors has been demonstrated in the laboratory (information vs. raw data transmission).
**Objective**
Design intelligent sensor network with embedded process-knowledge at the sensor level. Decentralize process decision making.

**Design**
- Complex processes broken down into simpler, smaller processes. Relationship rules are created to link all processes to overall process.
- Share process knowledge/information among sensors and controlling equipment via wireless communication.
- Process health monitoring done through individual sensor performance and process knowledge rules.

**Status**
- Process composed of 2 sub-processes and 6 measurements have been modeled and implemented.
The ISHM approach provides for vast enhancements in reliability, and reduction of maintenance and operational costs in vehicle and surface support equipment. NASA recognizes the potential of ISHM technologies and supports the development of specific subsystems and components.

ISHM architecture consists of traditional and smart sensors, software, and computing that enable the monitoring and management of systems.

The ISHM effort supports the goals of autonomy, modularity, and re-configurability desired by the Exploration program.

Smart Sensors are designed and developed following the above criteria, supporting the determination of nominal/off-nominal behavior so that other systems can take appropriate actions.

The combination of Smart Sensors and ISHM technologies presents the optimal approach for success.