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On Representative Spaceflight Instrument and Associated Instrument Sensor Web Framework[1,2]

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Abstract—Sensor Web-based adaptation and sharing of space flight mission resources, including those of the Space-Ground and Control-User communication segment, could greatly benefit from utilization of heritage Internet Protocols and devices applied for Spaceflight (SpaceIP). This had been successfully demonstrated by a few recent spaceflight experiments. However, while terrestrial applications of Internet protocols are well developed and understood (mostly due to billions of dollars in investments by the military and industry), the spaceflight application of Internet protocols is still in its infancy. Progress in the developments of SpaceIP-enabled instrument components will largely determine the SpaceIP utilization of those investments and acceptance in years to come. Likewise SpaceIP, the development of commercial real-time and instrument co-located computational resources, data compression and storage, can be enabled on-board a spacecraft and, in turn, support a powerful application to Sensor Web-based design of a spaceflight instrument. Sensor Web-enabled re-configuration and adaptation of structures for hardware resources and information systems will commence application of Field Programmable Arrays (FPGA) and other aerospace programmable logic devices for what this technology was intended. These are a few obvious potential benefits of Sensor Web technologies for spaceflight applications. However, they are still waiting to be explored. This is because there is a need for a new approach to spaceflight instrumentation in order to make these mature sensor web technologies applicable for spaceflight. In this paper we present an approach in developing related and enabling spaceflight instrument-level technologies based on the new concept of a representative spaceflight Instrument Sensor Web (ISW).

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1. INTRODUCTION

In this paper, we present the new concept of Instrument Sensor Web or ISW. There are a few intuitive reasons for an ISW. For example, building blocks of an instrument suit of sensors and signal processing electronics can intuitively be viewed as a sensor web, with heterogeneous sensors and with a combination of new and heritage heterogeneous electrical wire and wireless interfaces. The topologies for these hardware and information systems building blocks can be developed into enabling ISW architectures. Such architectures will result in low cost, reliable and intelligent on-board data pre-processing, solid state recorder multi-function data housing and alternative data compression schemes on more than one input data stream within the Instrument Data Processing Unit (IDPU), and data downlink protocols based on SpaceIP [8]. In this paper, we present the

1 U.S. Government work not protected by U.S. copyright
2 IEEEAC Paper # 1110, Version 2.0, Updated October 25, 2006

outline of the theoretical framework for an ISW and the architecture of its FPGA-based signal and information processing building components.

The heritage state-of-the-art view of a Sensor Web is that of a Distributed Instrument (a conglomerate of instruments, or a constellation of spacecrafts) [2] comprised of many instrument-alike smart sensors and interconnected by a heterogeneous communications system.

We describe in this paper a new and different view of a spaceflight instrument as a sensor web, called the Instrument Sensor Web. This is a view of an instrument as a sensor web not only from the science perspective and benefit, but also from the engineering perspective. Instrument components, enabled by powerful computational and communication modules, become nodes within the instrument discipline-subsystems (sub-webs) and turn these interconnected sub-webs into an ISW. The instrument itself can then make use of sensor web enabling functionality based on feedback, in-situ analog signal and digital data processing and event detection in real-time, on-board the spacecraft. ISW allows extraction of useful, reliable and timely information from the ISW in-situ sensors, as opposed to today's "transmit-only nodes" and "long-time-range detection on the ground" paradigms. It allows the instrument structure adaptation to its environment which, in turn, identifies a new information system technology domain and which enables new observation measurements through the ability to reconfigure on-board instrument resources and facilitate access of ISW resources as nodes on the Internet. The ISW increases the accessibility and utility of science and engineering data at an instrument component level, as well as it is reducing risk, cost, size and development time for a payload and ground-based information systems.

There are presently just a few operational spaceflight sensor webs, such as the National Aeronautics and Space Administration (NASA) EO-1 and Terra pair of satellites, because they happened to have two comparable instruments – the moderate resolution imaging spectroradiometer (MODIS), with *a day in response time.* The NASA Tracking and Data Relay Satellite System (TDRSS) is another example of a sensor web in space comprising four spacecrafts. The DOD Global Positioning System (GPS) presents an inspiring example of usefulness for each of its 24 operational satellites to carry the constellation common almanac, making it an intelligent sensor web node. A GPS user, locking on a single visible to this user GPS space vehicle, can obtain the almanac for the entire constellation. An ISW enables a spaceflight mission as a global sensor web with real-time response.

Based on the concept of ISW, we describe the theoretical framework of ISW and a framework for a software engineering tool, which facilitates an instrument analysis and synthesis as an instrument sensor web on the precedent of the Ocean Carbon, Ecosystems and Near Shore processes (OCEaNS) class missions.

This concept will also be validated on the precedent of the Magnetospheric Multi-Scale (MMS) mission Fast Plasma Investigation (FPI) suit of instruments.

2. On Heritage State-of-the-Art Sensor Web Fundamentals

Following is a description of the heritage state-of-the-art concept of Sensor Web as a Distributed Instrument, followed by a diagram depiction of the new concept of a Sensor Web for a spaceflight representative instrument – an instrument complex enough to be interpreted as a sensor web,

2.1 The Heritage Concept of a Sensor Web

The Sensor Web concept originated at the National Aeronautical and Space Administration Goddard Space flight Center (GSFC) in 1995 and led to a technological breakthrough in conducting remote measurements. Sensor Web technology has thus been around for a while, with a proliferation of terrestrial sensor webs in recent years. The heritage concept of a sensor web is that of a distributed instrument [2] and the sensor web state-of-the-art is encompassed by the following heritage concepts, views and definitions:

- A standard vision of wireless sensor networks involves an end-user buying a collection of sensor nodes and gateways, powering them up, and sprinkling them literally and figuratively – within an environment.

- The Sensor Web is a new type of Geographical Information System (GIS) that can be embedded into an environment to monitor and control it. A spatially distributed, synchronous instrument can react and adapt to changing environmental conditions. The pod (node) instruments comprise the distributed instrument. Sensor Web is a new class of distributed instruments for monitoring and exploring environments.

The state of the art heritage sensor web concept is depicted in the following Figure 1 (Open Geospatial Consortium (OGC) White Paper [4]) and in Figure 2 EEE-1451 Standard Overview [5]-[6]) and used here with authors' permission. Figure 1 demonstrates a set of interconnected terrestrial instruments, spacecrafts and ground stations comprising a global sensor web. Figure 2 demonstrates a proposed for the IEEE standard smart sensor model (for a terrestrial instrument node). Figure 3 demonstrates the new concept for a spaceflight Instrument Sensor Web.

Standardization of sensor web components is underway – mainly at the U.S. National Institute of Standards and Technology and the Open Geospatial Consortium, Inc., [4]. Following in Figure 2 is their proposed model for Smart Transducer Interface Module.

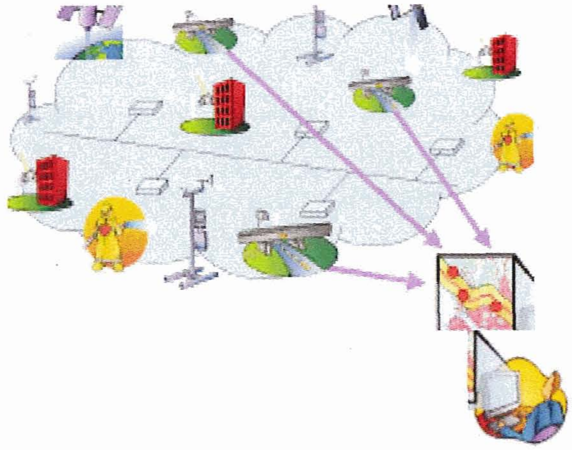


Figure 1. Sensor Web Enablement

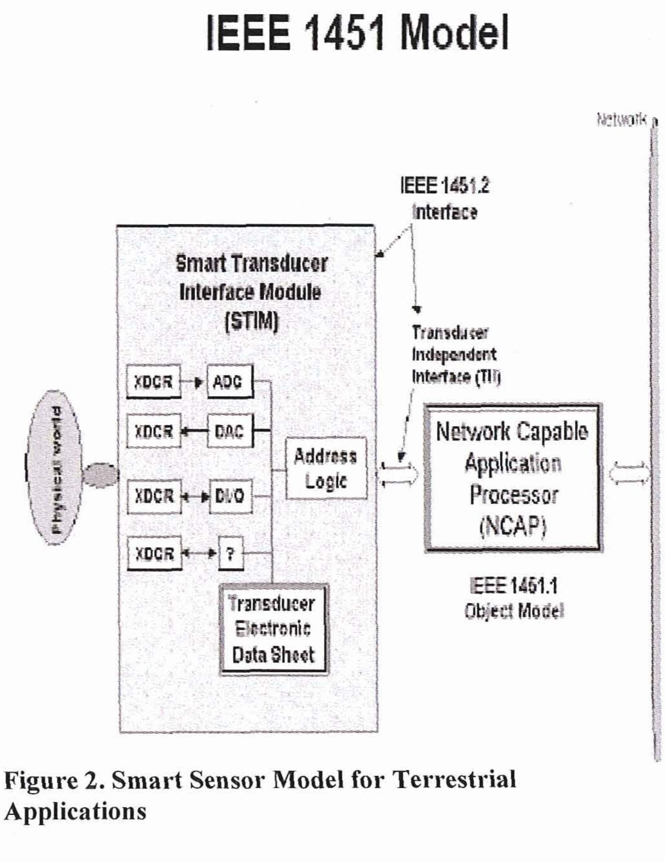


Figure 2. Smart Sensor Model for Terrestrial Applications

3. On Spaceflight Representative Instrument Sensor Web Fundamentals

There has not been yet an instance of an instrument being viewed or designed as a sensor web. Because we propose this new concept, it is the appropriate time to start with developing the theoretical framework for this concept domain. The heritage space flight instrument is a "transmit-data-only" node with a "long-time-range event detection on the ground" paradigm.

The new paradigm being described in this paper is based on a two-way communication between nodes within a spaceflight instrument and on-orbit rapid extraction of useful information. The new paradigm will exploit the heritage sensor web by adopting many of its concepts and models (Figure 1, Figure 2), while enabling improved consistency, portability and re-configuration within spaceflight instruments (Figure 3).

The cardinal idea is that each instrument discipline-subsystem, such as thermal subsystem, power subsystem and flight data subsystem, as well as other subsystems, can be viewed as a sensor sub-web comprising the Instrument Sensor Web. Other nodes within or outside the instrument sensor web can then independently address each node in an instrument sensor web.

The Instrument Sensor Web provides such new capabilities such as:

- Enables bi-directional digital communications to simplify wiring/harness and *facilitates battery-powered sensors on rotating (moving) components, reducing interconnect cost and introducing new sensing capability in locations not accessible before*
- Enables self-description of sensors in a network by built-in Transducer Electronics Data Sheet (TEDS) and *allows smart sensors integration into different networks*
- Enables embedded processors for on-board data pre-processing and *feedback-based actuation, which allows self-evaluation and fault prediction and detection*
- Enables the *time-stamping of measurements at the signal source*
- Eases re-configuration and functional flexibility and *intelligent use of redundancy for alleviating single-point failure designs and improved reliability*
- Facilitates communication of information in standardized digital format

- Eases Internet connectivity for *global access of instrument sensor information.*

The following Figure 3 conceptually represents the Instrument Sensor Web

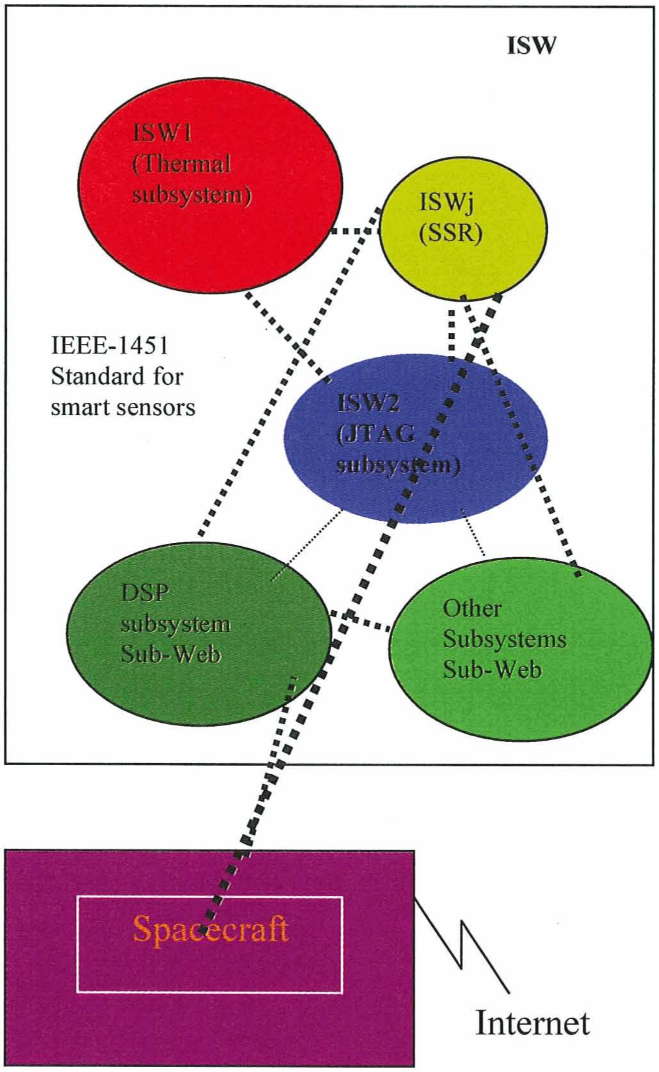


Figure 3. Spaceflight Instrument Sensor Web Concept Enables any Mission as a Sensor Web

3.1 Representative Instances of Instrument Heritage Sub-System Sensor Webs

From the engineering perspective, the sensors, even for a single optical instrument, are *distributed* in different focal planes or different locations in the same focal plane. This, in turn, enables a view of an instrument on-board a spacecraft or multiple instruments on-board a formation of spacecrafts as an *Instrument Sensor Web and also provides a systematic beneficial connection between Sensor Webs and Earth Science projects, be to on a planet surface or for Space Flight, or both.*

Even heritage instrument discipline-centered subsystems are amendable to the ISW concept as described below.

3.1.1 Utilization of Sensor Web Heritage for Instrument-Level Sensor Webs

The new theoretical framework for instrument sensor web will encompass the heritage sensor web theoretics, for example, the theory under development at Stanford University [3], as well as recent developments described in [4]-[6].

An Instrument Sensor Web is an integrated system of real or *virtual* instrument components interconnected as sensors in a sensor web. These components can be on the integrated circuitry chip level (ICC) or printed circuit board level (PCB), or an instrument data processing unit (IDPU), or instrument level. They are enabled to interact with each other using communication protocols. The goal of the ISW is the specification of web service-based interoperability framework to integrate instrument components into an instrument sensor web infrastructure.

The ISW framework will ensure instrument decomposition into modules and identify the interconnections. Multi-purpose information encoding and likewise flexibility enabling is the most important driver for this framework, namely, flexibility in configuration of the number of source phenomena data channels, flexible Signal-to-Noise-Ratio (SNR) selection and flexible instrument configuration.

3.1.2 Heritage Instrument Infrastructure as Instrument Sensor Sub-Webs

The heritage instrument infrastructure is discipline-oriented and comprises the thermal subsystem, the mechanical subsystem, the electrical subsystem, to name a few. These can be viewed as instrument sensor sub-webs:

- The infrastructure of an instrument Thermal Subsystem comprised of RFID thermistors, heaters and RFID READER control nodes

- The instrument Integration and Test Subsystem (JTAG) described in detail in Section 3.2

- The Focal Planes comprised of mega-pixel detector sensors and associated readout electronics circuitry comprise another functional sub-web

- The Solid State Recorders (SSR) data store subsystem is a web of virtual sensors that is sharing its memory resources while constantly monitoring each other utilization status. Any authorized node on the Internet World Wide Web can then interrogate these nodes for information of interest.

3.2 JTAG Subsystem as an Instrument Sensor Sub-Web

The ISW allows viewing an instrument heritage sub-system as a sensor web. For instance, the sub-system of Joint Test Action Group (JTAG) standard-enabled devices (nodes, pods) can be viewed as a sensor web which facilitates a transparent sensor web integration and testing infrastructure for instrument systems that otherwise would be extremely complex for Integration and Testing (I&T). A JTAG-enabled devices sensor sub-web within an instrument facilitates the instrument intelligent Integration and Testing (I&T).

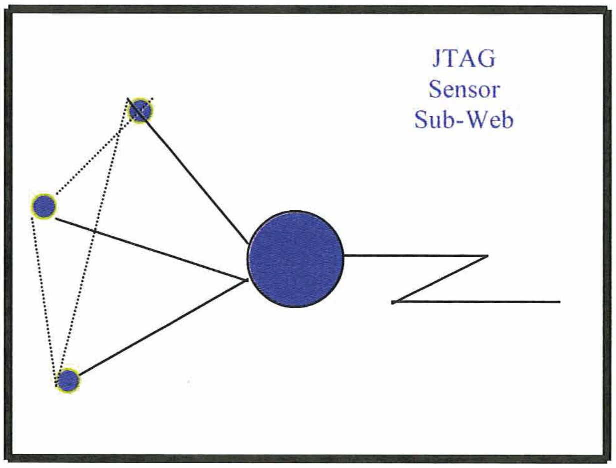


Figure 4. JTAG Sensor Sub-Web

3.3 Thermal Subsystem as an Instrument Sensor Sub-Web

Each smart Radio Frequency Identification (RFID) label with *integrated temperature sensor* or thermistor suit $\{T_1, T_2 \ldots T_n\}$, when illuminated from a central node $\{READER\ T_0\}$, broadcasts a communications packet with its ID and isensed temperature value:

** Thermistor ID T_i * Temperature digital value **

For example, the commercial tags operate at 13.56 MHz and are compatible with the ISO15693 standard. The sensor, microchip, battery and antenna are integrated into a paper-thin label at a low cost. The thermal subsystem sensor sub-web is the depicted in Figure 5. *Integration and Test Sensor Sub-Web within the Instrument Sensor Web*, as well as *On-Board Super-Computing Sensor Web Topologies* can be demonstrated likewise the thermal sub-web. The remaining instrument subsystems, such as power distribution, focal planes, on-board solid state recorder (SSR) data storage subsystem and others will also be analyzed from instrument sensor web point of view, once the instrument sensor web theoretical framework is developed further.

What can one thermistor tell to another thermistor? For example, when no broadcast message is received from a known thermistor it may indicate that it lost power. A thermistor may itself turn on/off based on adjacent thermistors state messages in an intelligent thermal control sensor web. When two thermistors are on opposite sides of a plate they can establish the heat transfer gradient, when "talking" to each other, and request actuation of nearby survival heaters.

Instruments may comprise heterogeneous distributed sensors, which are communicating among themselves and spacecrafts' Command and Data Handling computer (C&DH) over heterogeneous communications channels.

This new view is also applicable to multiple instruments on-board a spacecraft or a constellation of spacecrafts, or instruments in planetary atmosphere, at sea and on a planetary terrain.

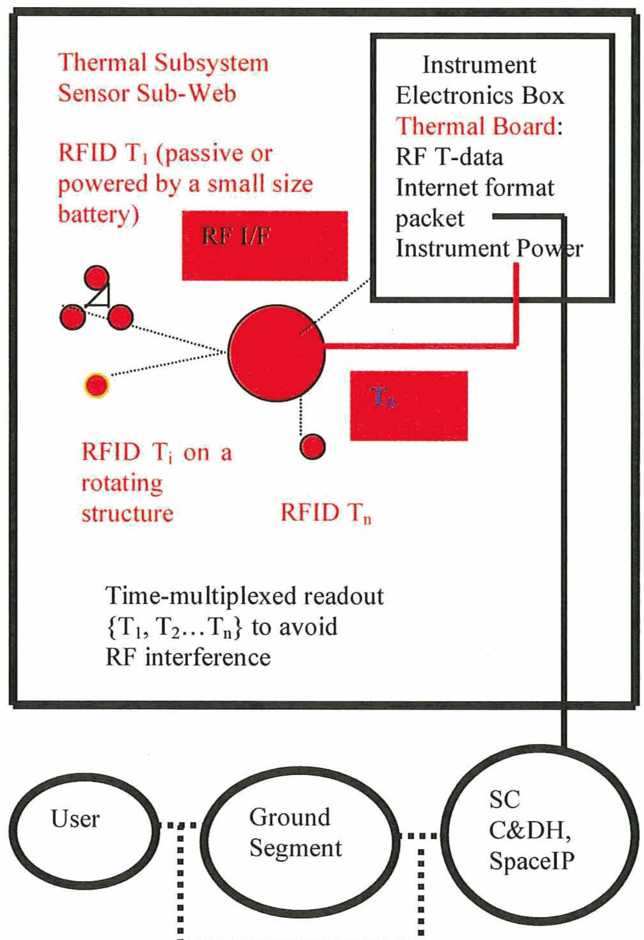


Figure 5. RFID with Integrated Thermistors Sub-Web within a small confinement of an instrument and reachable by Control node T_0

4.0 OUTLINE OF THE INSTRUMENT SENSOR WEB THEORETICAL FRAMEWORK

The theoretical framework will encompass instrument sensor web-enabled end-to-end components functionality, based on real-time on-board feedback, as compared with only collecting and forwarding data to the ground station:

- Sensing of natural science phenomena and instrument internal engineering states, such as temperature and power usage by instruments and electronic boxes
- Extraction of novel event information from sensor signals and data
- Instrument storage in SSR and communication of what is novel as opposed to bulk storage within spacecraft SSR
- Real-time computation of burst parameters and making relevant decisions based on on-board detected events.
- Act on the decisions and evaluate results

Building Blocks and Functions

- Pods, inter-node communications, in-situ information conditioning and processing

Communications

Following Claude E. Shannon's "The Mathematical Theory of Communication" [1], we consider such building blocks of Sensor Web:

- Sensor as Information Source, Communication, Noise Source for communications signal on communication channel, Sensor as Information Receiver, *Networked information processing*

Sensor Web Nodes

- Sensor Web Model, n x n Matrix, Graph Vertices, Logic Tree, Finite Algebraic Field, Electrical Network

Sensor Web Feedback

- Feedback mechanism between nodes is the bases for sensor web adaptation and evolution.

Sensor Web Protocols

- We will use heritage protocols and SpaceIP [7]-[8] for space/ground link. For inter-node communication protocols, we plan to work with NIST and OGC to develop new Sensor Web Standards, similar to GIS, Sensor Web Enablement (SWE), Sensor Web Language (SWL), the Prime standard for data representation and exchange on the Web (XML) and the OGC Sensor Language SensorXL. Legacy protocols (serial synchronous and asynchronous) can be converted in hardware into Internet protocol packets.

4.1 ISW Theoretical Framework Development Outline

The theoretical framework will be developed in two ways - to include the common features found today in heritage sensor webs and new ISW features, as well as an engineering tool for instrument requirements analysis and synthesis into an instrument sensor web. These features include re-configurable functionality pods, adaptable inter-node communication links, and information exchange protocols. In summary, the theoretical framework and engineering tool intend to enable the instrument analysis and synthesis as an instrument sensor web, resulting in new science and new engineering possibilities. It will analyze a representative space flight instrument for earth sciences investigations into an ISW, including the development of an instrument sensor web analysis software tool.

5. ON INSTRUMENT SENSOR WEB COMPONENTS AND ARCHITECTURES

This new view of an instrument as a sensor web is amendable to deep space and near-earth science missions (especially the missions presently in proposal phase) such as Ocean Carbon, Ecosystem and Near Shore processes mission (OCEaNS). These remote sensing missions invariably carry a set of different sensors with some sensors being multi-detector sensors such as CCDs and CMOS mega pixel/detector arrays, InGaAs linear mega pixel/detector arrays. Each array mega-pixel measurements are being multiplexed into a smaller, but still multi-channel outputs for digitization by multiple ADCs. These sensors and the associated analog and digital signal processing electronics' building blocks can be viewed as an Instrument Sensor Web with Heterogeneous Sensors and Heterogeneous Interfaces in combination of heritage printed-circuit connections and wireless interfaces. The topologies for these electronics building blocks can be developed into enabling smart sensor architectures, which will result in cost, redundant and intelligent on-board data processing, solid state recorder multi-function data housing, multiple data sources compression, and data downlink SpaceIP protocols compatible with the Internet. The Laser Interferometer Space Antenna (LISA) with three spacecrafts in locality of a single orbit plane and the Magnetospheric Multi-Scale (MMS) mission comprising a constellation of four spacecrafts carrying near-identical electronic modules are natural instances of an evolving Sensor Web Architecture for extreme environments. Another area of applicability of ISW is a robotics system, supplemented and enabled by an environmental Sensor Web, which communicates with the robots, providing the robots with direct information about the robots' unstructured environment. The Robotics On-Orbit Materials Processing System (ROMPS) payload flown in space before, can be used as a robotic platform for such a sensor web concept validation, as well as the Goddard Robotic Applications Terrain Facility. We also envision the development of the signal and information processing electronics aspect architecture with an implementation for earth sciences' representative spaceflight mission smart readout and information pre-processing integrated circuitry, namely the ROIC with ISW communication module infrastructure on the ROIC, as described in Section 5.1.

The Instrument Sensor Web component developments comprise:

- Development of a radiation hardened ROIC topologies for Near IR InGaAs linear detectors array, with each ROIC having an integrated communications module (CM) with an Internet Address and On-Sensor digital data processing and reformatting capabilities for direct communication to a Solid State Recorder (SSR)
- Development of a Sensor Signal Conditioning Electronics Component Communications micro-protocols over Multi-Channel network
- Optimize an RFID based sensor digital message detection and recognition
- Implement a high volume and rate data compression and switching for a 1Gbs Ethernet.

This new view of an instrument as a sensor web is also applicable to multiple instruments on-board a spacecraft or a constellation of spacecrafts, or instruments in a planetary atmosphere, at sea or planetary terrain.

A mission like the Laser Interferometer Space Antenna mission (LISA) with three spacecrafts in locality of a single orbit plane and Magnetospheric Multi-Scale mission (MMS) comprising a constellation of four spacecrafts carrying identical electronic modules are natural instances of an evolving Sensor Web Architecture for extreme environments.

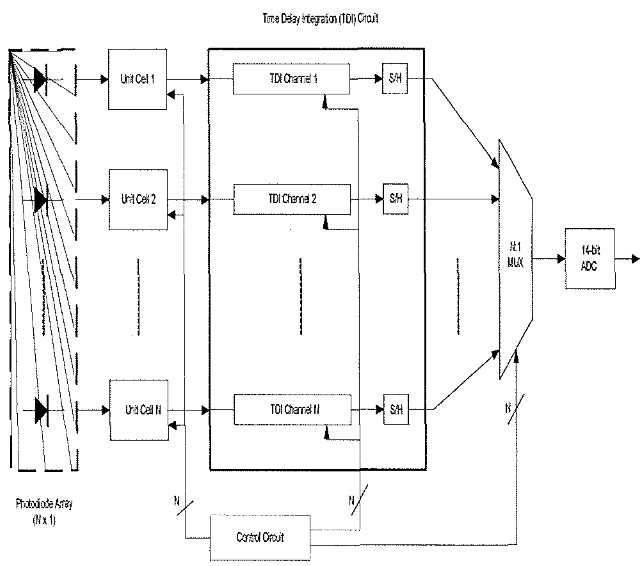
Another area of applicability is a robotics system, supplemented and enabled by an environmental Sensor Web, which communicates with the robots and provides the robots with direct information about the robots' unstructured environment. The available Robotics On-Orbit Materials Processing System (ROMPS) payload can be used as a robotic platform for such a sensor web as well as the Goddard Robotic Applications Terrain Facility.

We outlined the development of the signal and information processing electronics aspect architecture with an implementation for earth sciences' representative spaceflight mission smart readout and information pre-processing integrated circuitry, namely the ROIC with ISW Communication Module infrastructure on the ROIC.

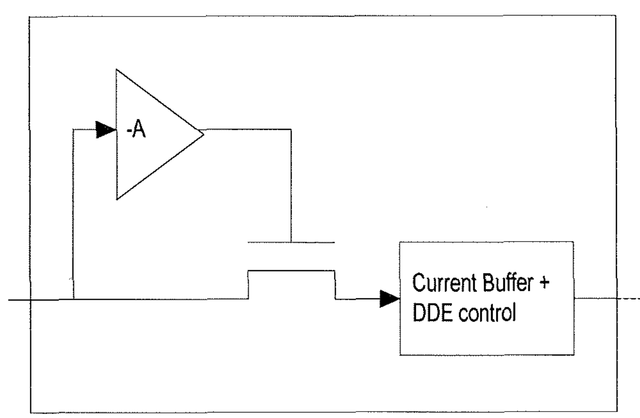
It is time to enable a spaceflight instrument with ISW technologies and go beyond the Personal Computer devices networking a remote mouse, a remote keyboard, remote Internet access and a suit of plug-and-play external storage.

5.1 ISW ROIC Component Concept

Presently there is no commercially available flight qualified ROIC for InGaAs detectors. The concept presented here depicts such a design in the context of an instrument sensor web smart node. The ROIC comprises the Unit Cells and the Time-Delay-Integration (TDI) Channels. The digital data electronics (DDE) is imbedded in the Unit Cells. The capacitance trans-impedance integrated amplifier (CTIA) is imbedded in the TDI Circuit's TDI channel. The InGaAs photodiode sensor array analog signals are processed by the smart ROIC comprised of the Unit Cells, TDI Circuit, Multiplexer and ADC (output is made RF-ready for the ROIC node communications). The Unit cell and the TDI Channel blocks are also depicted below separately.



Unit Cell



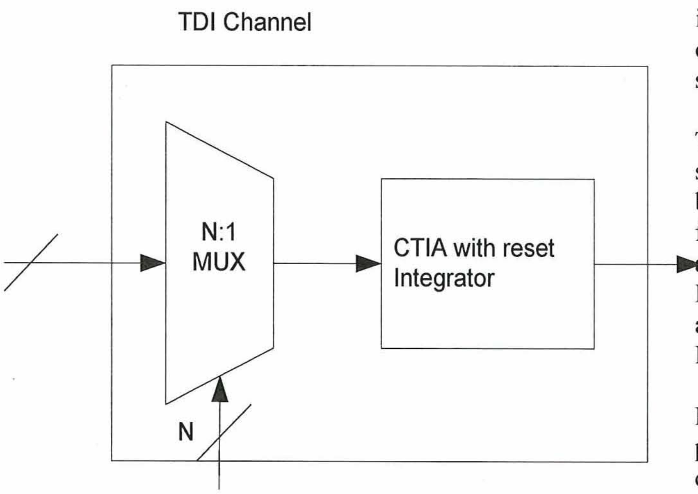


Figure 6. Near IR Smart Sensor ROIC Schematics

5.2 Smart Sensor ROIC Pre-Processing and Communication Modules

Instrument Sensor Web addresses the important aspects of adaptability and intelligence in a sensor network. The system works through wireless and hard-wired mechanisms. There are five components of this system, namely (1) sensor array (2) Level 1 data processing station (DPS) (3) Level 2 DPS (4) software console with system configuration data, Graphical User Interface, database of collected sensor data and log/report generation (5) Built in Self Test (BIST). The automatic re-configurability of the sensor web is achieved through data processing algorithms that are run at the work station and on the central processing stations, by utilizing a board with 32 bit micro-controller, FPGA, Flash ROM and on-board memory device. Some of the tests performed to ensure the fidelity of results include persistence (time measurement), strength (amplitude measurement) and synchronization tests. DPS board is the heart of the complete system. It initiates configuration loads to each sensor in the network. It contains the wireless protocol management functions and extracts appropriate Packet Data Units from the wireless communication interface of each sensor board. DPS boards take into account the wireless protocols such as 802.11 and ensures free flow of transmit and receive functions. Receive function is from the sensor array to the DPS board and while the transmit function is from DPS board to other DPS boards and to the workstation with software console. The transmission from DPS boards can be made secure by adding algorithms such as Manchester encoding and/or DES, to the data, prior to transmission. Level 2 DPS board interfaces with one or more Level 1 boards, wherein Level 1 boards are processing mobile device frequencies whereas Level 2 boards are processing RFID tag information.

By enhancing the antenna at each sensor, the sensor can adapt to multiple inputs (multiple frequency bands), such as mobile devices, pagers, RFID, Bluetooth and WI-FI.

Another low-cost alternative is to utilize multiple antennas on the sensor boards. For future extensibility beyond 3 GHz, in order to make it suitable for high frequency applications, diodes could be used for frequency conversion of input signal.

The ISW system can detect and reduce unwanted noise and signal distortion that can arise due to the multiple frequency band support and the interference caused by nearby frequency bands. This is achieved by using a RF front-end at the sensor board with Automatic Gain Control (AGC), Low Noise Amplifier (LNA), Wideband Amplifiers and appropriate RF switches or a high resolution Analog-to-Digital Converter (ADC).

Besides stability and gain, it is often required to have a preamplifier with low noise figure so that it has a less dominant effect on the overall noise figure of the system. Hence, we used low noise amplifiers.

For the Broadband application as stated above, we may be required to implement a Broadband Transistor Amplifier design. These can be achieved with Balanced or Distributed Amplifiers.

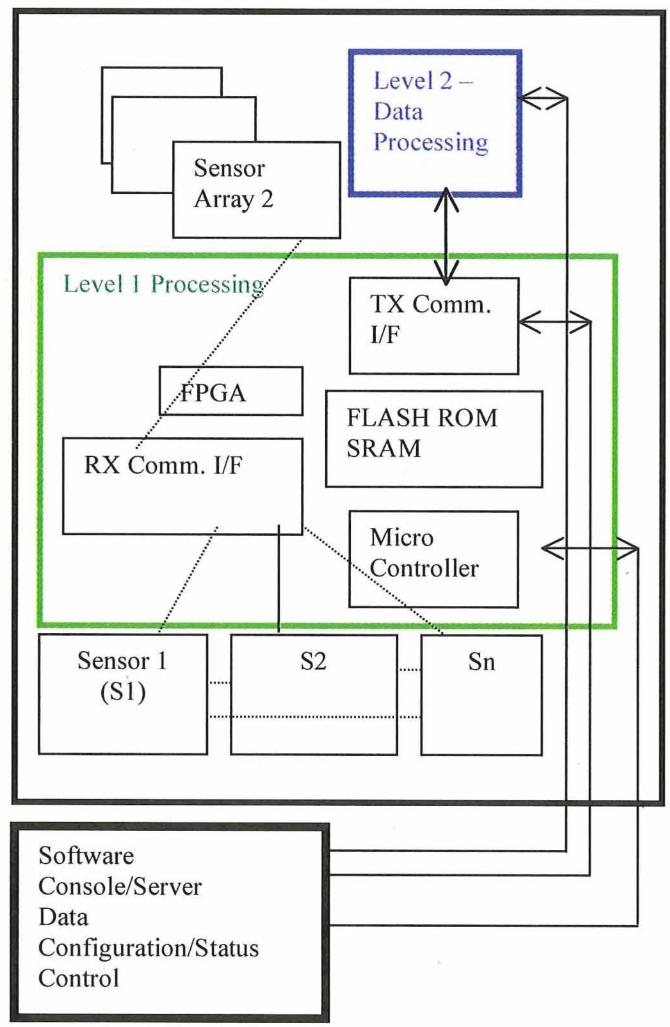


Figure 7. Intelligent/and Adaptable ISW System Level

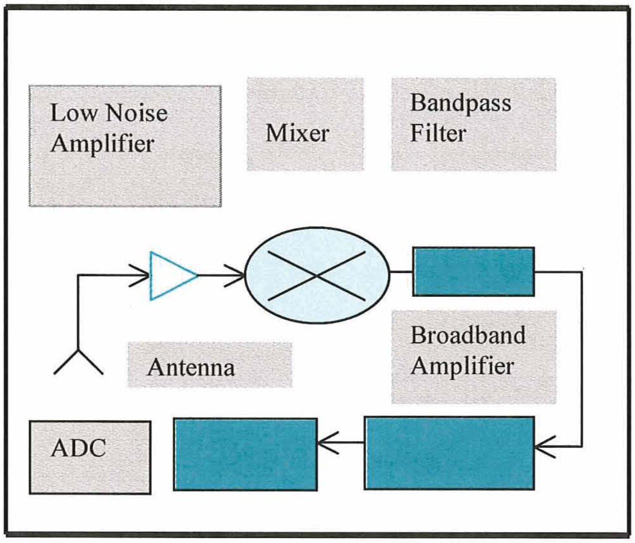


Figure 8. RF Front end for improved SNR

CONCLUSIONS

We have presented a new concept of a spaceflight instrument as an Instrument Sensor Web. We have also outlined the theoretical framework for the Instrument Sensor Web and described basic architectural topologies for Instrument Sensor Web components. We presented the case for Instrument Sensor Web implementation for a few representative spaceflight instruments and applicability to missions now in proposal or study phase. Future work comprises the development of the ISW theory and the development of an engineering tool to be used in Instrument analysis and associated ISW synthesis.

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BIOGRAPHY

Semion Kizhner is an aerospace engineer with the National Aeronautics and Space Administration at the Goddard Space Flight Center. He proposed the development of the Hilbert-Huang Transform Data Processing System and has been leading the HHT-DPS development team. He participated recently in evaluation of the NASA Advanced Space Technology proposals. He published a dozen of technical papers and mentored numerous undergraduate, graduate and doctoral students in the NASA Education Programs. He graduated from Johns Hopkins University with an MS degree in computer science.

Madhavi 'Meg' Vootukuru is a founder of Syneren Technologies Corporation, a company providing high quality engineering and program support services to DoD and other federal agencies as well as commercial customers. She has a Bachelor of Engineering degree from Osmania University, India where she graduated with a gold medal at the top of her class. She graduated from University of Cincinnati, with a Master of Science in Electrical and Computer Engineering. She has over 10 years of industry experience in the fields of ASIC/FPGA/Microprocessor Design and Verification with companies like Digital Equipment Corporation and Motorola. She was a key contributor in the Alpha Microprocessor Design while at Digital and worked on Network Processors at Motorola. She has authored and reviewed several technical papers in conferences and Journals.

Umesh D. Patel was born in Navsari, India. He received the B.E. degree from the Maharaja Sayajirao University, Vadodra, India, M.E. degree from Maharaja Sayajirao University, Vadodra, India, M.S. degree in Electrical Engineering from The George Washington Universiy, Washington, DC, and D.Sc. degree from the George Washington University, Washington, DC. Since 1995, he has been working at Goddard Space Flight Center, Greenbelt, MD as Electronics Engineer. He has authored and co-authored papers in technical journals and conferences. His research interests are hysteresis modeling, low-voltage mixed-signal integrated circuit designs, radiation tolerant microelectronics and data conversion VLSI systems designs.