ISHM Implementation for Constellation System

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Integrated System Health Management (ISHM) is a capability that focuses on determining the condition (health) of every element in a complex System (detect anomalies, diagnose causes, prognosis of future anomalies), and provide data, information, and knowledge (DIaK) – *not just data* – to control systems for safe and effective operation. This capability is currently done by large teams of people, primarily from ground, but needs to be embedded on-board systems to a higher degree to enable NASA's new Exploration Mission (long term travel and stay in space), while increasing safety and decreasing life cycle costs of systems (vehicles; platforms; bases or outposts; and ground test, launch, and processing operations).

Related Definitions

Data

Comprise facts, observations, or perceptions (which may or may not be correct). Alone, data represent raw numbers or assertions, and may therefore be devoid of context, meaning or intent [1].

Engineering Data

Data that has been given an offset or amplification; data with engineering units.

Information

Includes data that possess context, relevance, and purpose. Information typically involves the manipulation of raw data to obtain a more meaningful indication of trends or patterns in the data [1]. Information pertains to known facts that result from processed data, and inferred facts from data by using knowledge and other facts.

Knowledge

Knowledge in an area is defined as justified beliefs about relationships among concepts relevant to that particular area. Intrinsically different from information [1], knowledge consists of facts and inference rules used for reasoning. Knowledge can be procedural, which refers to knowing how to do something, or declarative, which refers to knowing that something is true or false. We say we can access information, but only an agent possesses knowledge. Traditionally, knowledge has been associated with the concept of belief, which refers to statements that are inside the mind of an agent or can be inferred by the agent. These statements do not have to be true, and can be believed to varying degrees [2].

Related Definitions

Intelligent Sensor (IS)

A sensor that is network capable (can communicate over a network), and provides data, a measure of the quality of the data, and a measure of the health condition of the sensor itself. The IS integrates data, information, and knowledge (DIaK) local to it and from other elements in the network in order to achieve a maximum "degree of intelligence" (DoI). An IS with the highest DoI provides a complete an accurate measure of the quality of the data, and a complete and accurate assessment of its health. An IS may achieve its functionality by a combination of hardware and software elements, some of which may be located close to the sensor element (or transducer) and some at a distance. The IS may include the ability to self-reconfigure to overcome anomalies in its operation.

Intelligent Component (IC)

A component that is network capable (can communicate over a network), and provides a measure of the health condition of the component itself. The IC encapsulates DIaK needed to accomplish its local functions, and to be used by other elements in the network.

- The last Delta 4 to fly was the heavy-lift version, which blasted off from Cape Canaveral Air Force Station in December of last year. However, during what looked like a flaw-free ride to space, its first stage failed and its payload -- a mock weight simulating a satellite -- ended up 10,000 miles short of its target.

- The problem: fuel sloshing inside the booster caused some sensors to believe the rocket's tanks had run dry, shutting down the first-stage engines earlier than expected.

This is a case when a decision to shut down engines is done with limited information that does not take advantage of integrated awareness brought about by ISHM capability. Other relevant conditions such as the pressure in the tanks, signs of leakage in the tank and valves/pipes attached to it, other indicators that the engines and surrounding elements may (or may not) be entering a regime associated with fuel starvation, etc. could have been considered.
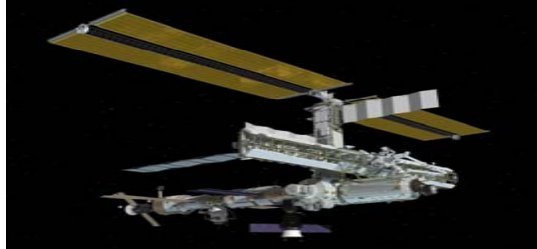
LAYERS REPRESENTING HOW ISHM IS CURRENTLY PERFORMED

Stennis Space Center

MOVE CAPABILITY TOWARD LEVELS 2 AND 1

	International Space Station	Rocket Engine Test Stand	
Layer 1 Vehicle/ Test Stand			Signal threshold violation detection
Layer 2 Astronaut/ Test Conductor			Added DIaK from on-board users.
Layer 3 Control Room			Added DIaK from broad group of experts.
Layer 4 Back Control Room			Added DIaK resources from larger community

ISHM capability, for the most part, does not imply advanced algorithms detecting anomalies with localized information, but rather it embodies autonomous integrated consistency checks throughout all system elements by a large number of rules, procedures, and simple models (algorithms) in a manner that is methodic, complete, and continuous. Additionally, an effective user interface must immerse the user in complete awareness of the condition of the system as provided by a credible ISHM capability.

Enterprise-Wide ISHM

- **Technology Development:** Research Centers/Universities.

- **Testbeds**: increase TRL, FCL, credibility and acceptance of ISHM capability.

- **ISHM-Enabling Engineering Design Process (IEEDP):** products delivered must include DIaK needed to determine the condition of the product, and to help determine the condition of other elements in the system.

- **ISHM-Enabling Systems Process (IESP):** must integrate products developed by the IEEDP and ensure inclusion of core elements to enable ISHM capability to evolve and improve throughout the life-cycle of the system (development and testing, to operation, to maintenance, to decommission).
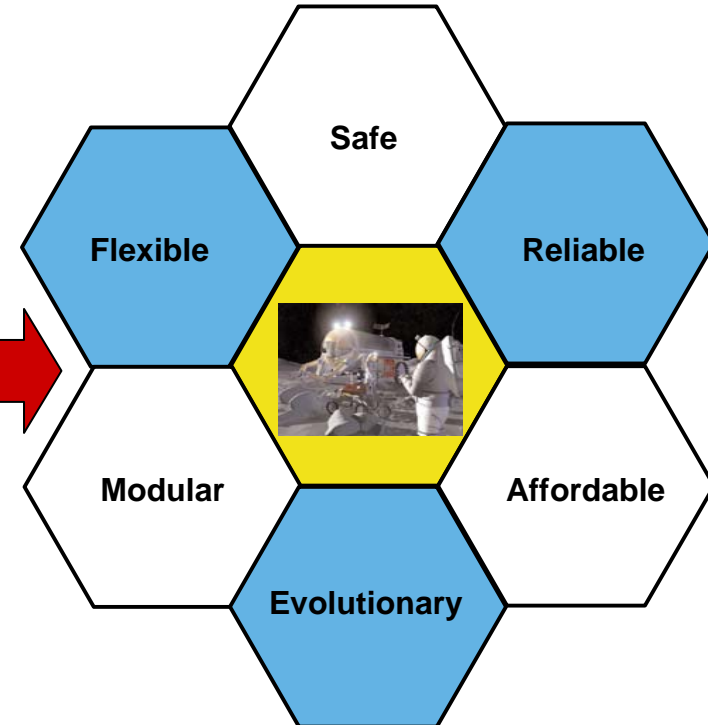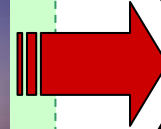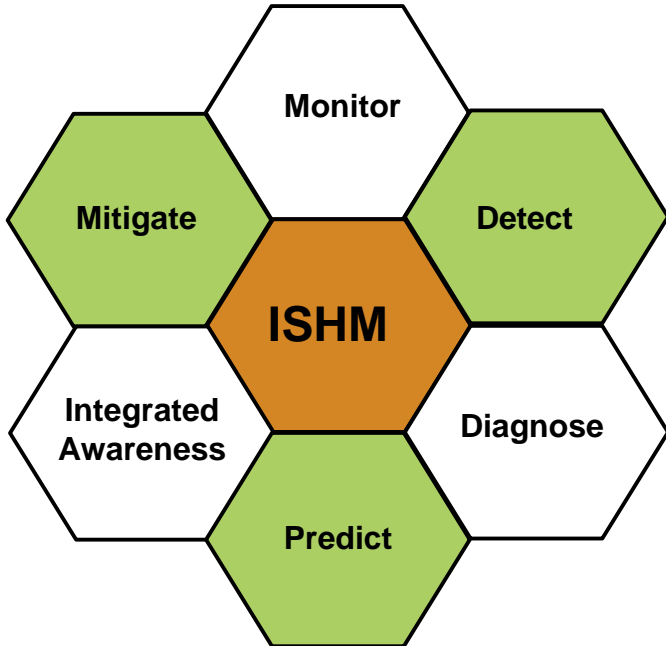
- RETS/ISS/LS should play a central role in developing and validating ISHM Capability and Technologies.
    - Extensive historical data and information to define a solid baseline prior to ISHM implementation.
        - Discrepancy reports (key knowledge of failure modes for HM Systems).
        - Test data (means of validation).
    - Expert Test Engineers (key participants to build knowledge bases and to experience and acknowledge ISHM benefits – should become advocates of the technology).
    - Complete and well understood models and documentation.
    - Suitable for staged implementation, e.g. the GN subsystem, followed by the RP subsystem, and so on.
    - Non intrusive implementation.
- RETS/ISS/LS can be established as permanent sites to test new ISHM elements such as "intelligent sensors," "intelligent components," system integration frameworks, etc. Adding new sensors or making modifications in RETS is much less complicated than in the case of flight hardware.
- RETS mirror the same tight integration found in the flight systems tested in these facilities (facilities replicate vehicle propulsion subsystems).

ISHM Testbeds & Prototypes at NASA SSC

Objectives

- Mature/Validate ISHM technologies on operational testbeds.
- Develop an integrating architecture/taxonomy/ontology (ATO) embodying networked intelligent elements.
- Develop a software environment to build ISHM models of systems.
- Develop prototype intelligent sensors.
- Demonstrate, gain user acceptance, and evolve ISHM capability on operational ground facilities.
- Provide portability to other Exploration Systems and Space Operations applications.

Approach

- Develop/mature core technologies
    - Intelligent integration architecture
    - Software environment
    - Intelligent sensors
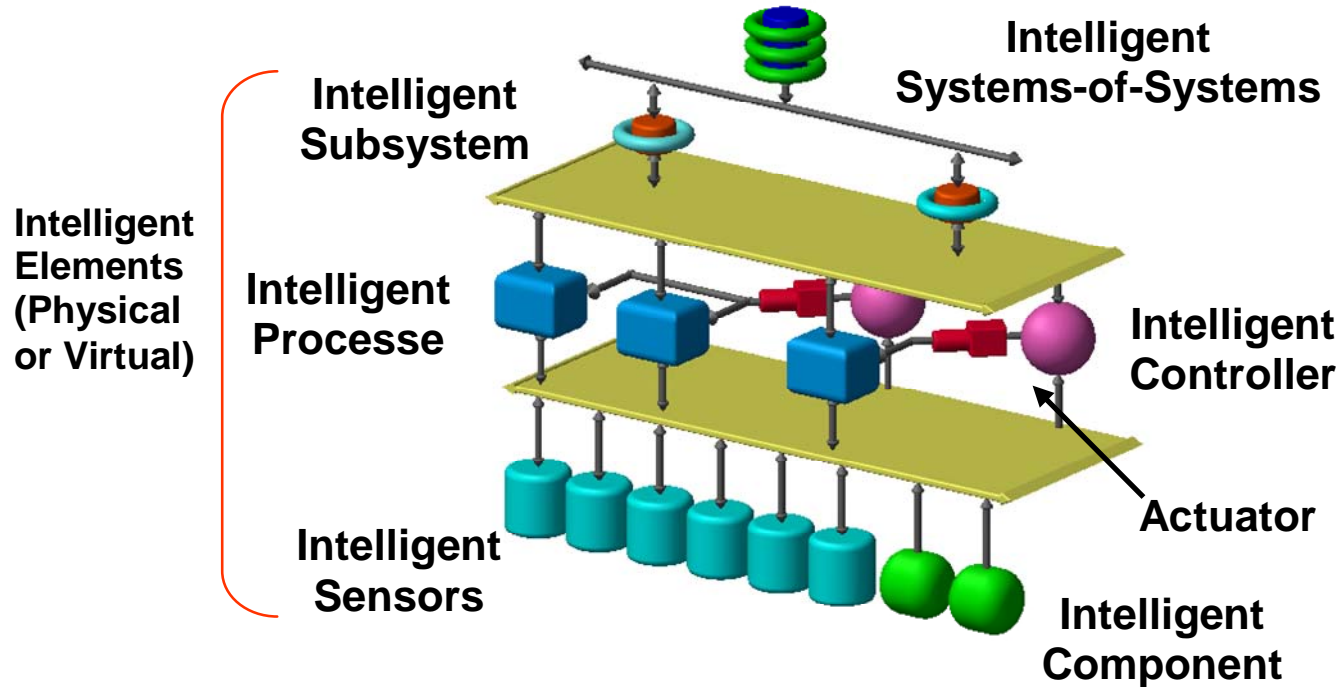- Establish testbeds: Rocket Engine Test Stands.

Benefits

- Trusted degree-of-safety determination
- Trusted margin of operation
- Reliable, integrated awareness of health of system's elements
- Validated data with unquestionable integrity
- Anomaly detection traceable to source
- Operational Testbed (Rocket Engine Test Stands) benefits from ISHM capability.
- Test stands ready to test ISHM-enabled test articles (engines, etc.).

Intelligent Systems-of-Systems

Intelligent Subsystem

Intelligent Elements (Physical or Virtual)

Intelligent Processe

Intelligent Controller

Actuator

Intelligent Sensors

Intelligent Component

SoS as Hierarchical Network of Distributed Intelligent Elements

Process models are generic. Components contribute boundary conditions (containment).

System of Systems

Intelligent System

Intelligent System

Bus

Intelligent Process

Intelligent Process

Intelligent Process

Bus

Intelligent Sensors

Intelligent Components

Tank Processes:

Fill

Pressurization

Over-Pressurization

Leaking

Pressure collapse

Valve Processes:

Opening

Closing

Leaking
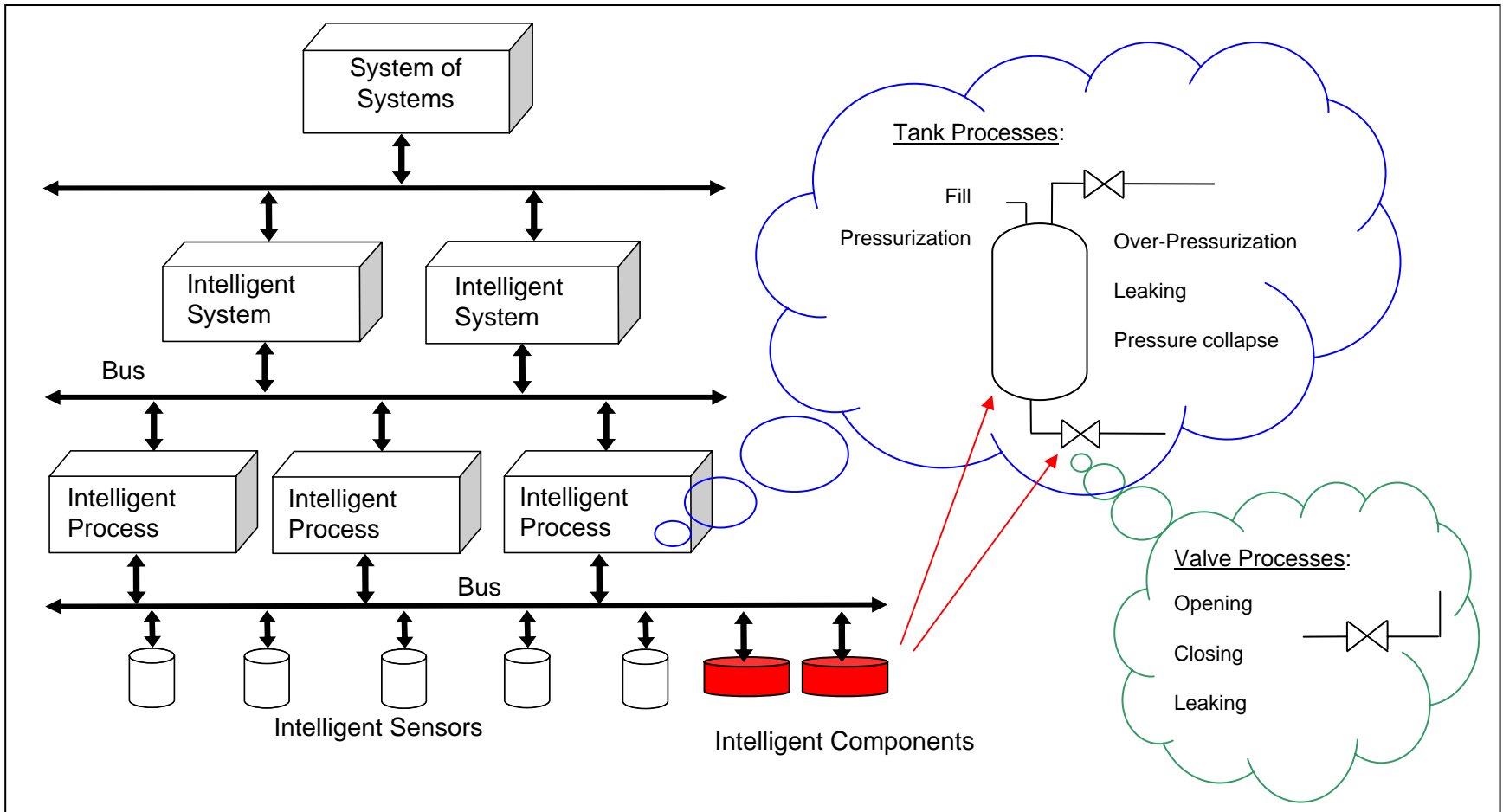
- IEEE 1451.X for networked intelligent sensors (physical or virtual).

  – Transducer Electronic Data Sheet (TEDS).

- Extensions of IEEE 1451 to address health condition as well as other system elements.

  – Health Electronic Data Sheet (HEDS).

  – Component Electronic Data Sheet (CEDS).

  – Controller Electronic Data Sheet (CtEDS).

OBJECT

Classes

Component | Sensor | Process

Tank | Valve | Pressure | Temperature | Electrical Resistance and Temperature | Tank | Pipe

Piezo | Strain-Gage | Thermocouple | RTD | Pressurize | Fill

Instance

Instances

LOX-E1-01
Sensors:
•Top Pressure
•Bottom Pressure
•Top Temperature
•Bottom Temperature
Processes:
•Pressurize
•Fill
Specs:
•Capacity
Rules:
Contents:
Condition:

PRES-TOP

TEMP-TOP

PRESSURIZE
Information Fusion:
•Analytical
•Statistical
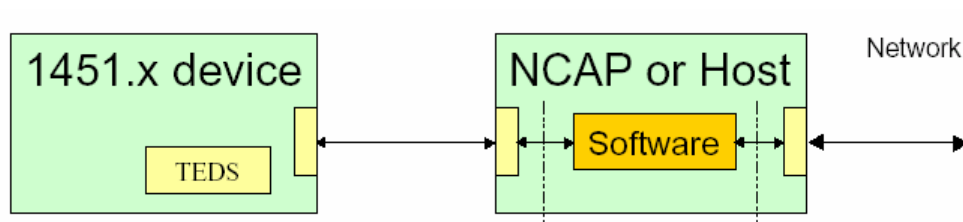•Qualitative
Rules:

Inheritance of conceptual understanding of process in sensor

- Intelligent Sensors
  - IEEE 1451
  - IEEE 1588

- Electronic Data Sheets
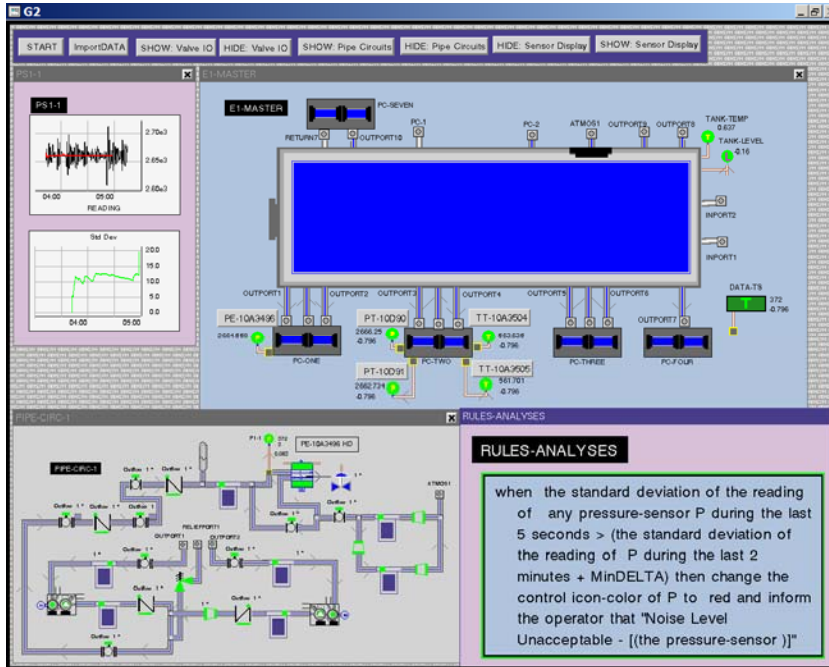 - IEEE 1451 TEDS
  - Extensions to TEDS: HEDS, CEDS

Testbed: E1 Rocket Engine Test Stand

Testbed: Portable Rocket Engine Test Stand

ISHM-Toolkit

- Encapsulates Data, Information, and Knowledge (DIaK) distributed throughout intelligent networked elements.
- Defined inter-element relationships are used to perform DIaK fusion (checking of inconsistencies).
- Multiple processes representing models (e.g. algorithms, rules, etc.) may run simultaneously to detect anomalies and infer health of each element.
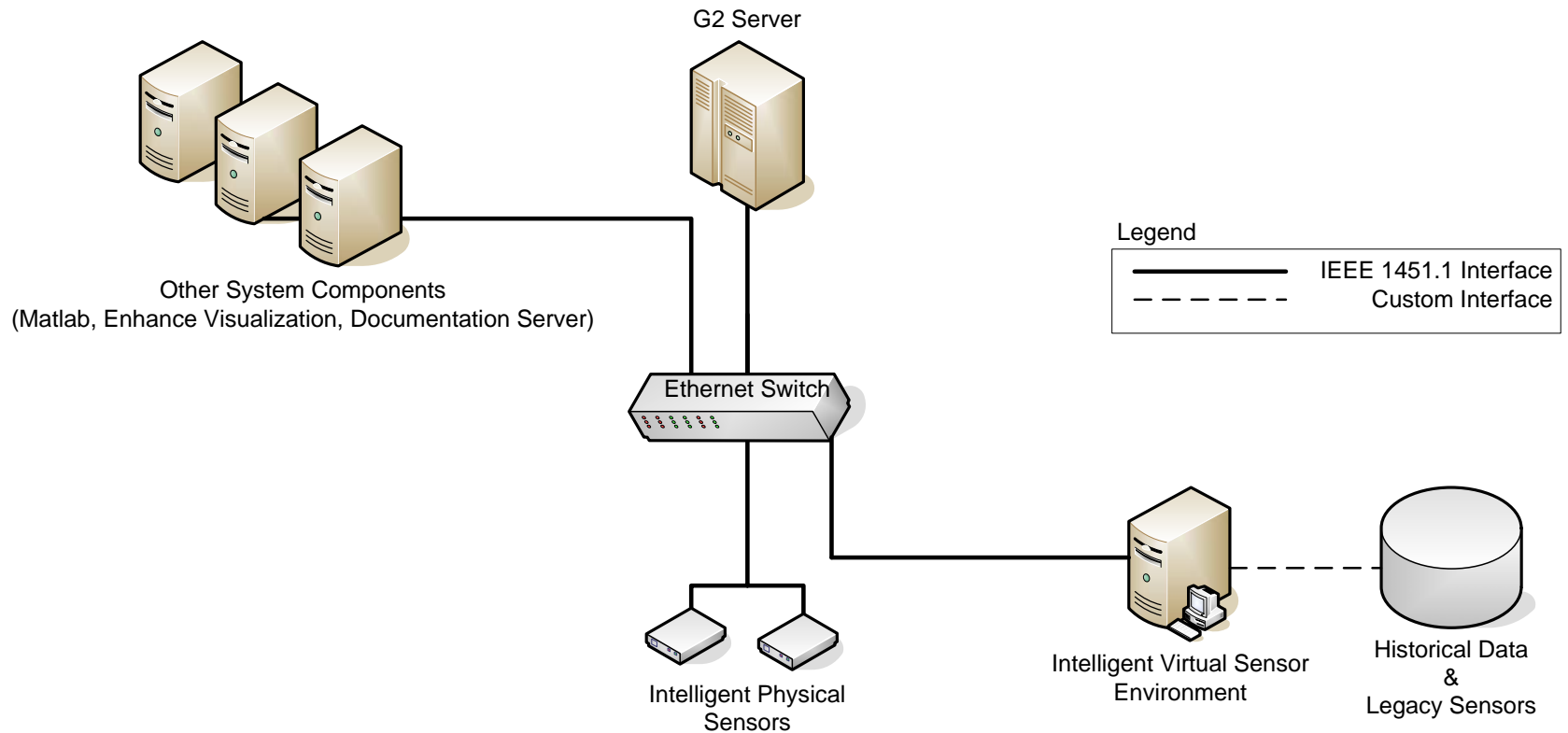
G2 Server

Other System Components
(Matlab, Enhance Visualization, Documentation Server)

Legend

————————	IEEE 1451.1 Interface
– – – – – – –	Custom Interface

Ethernet Switch

Intelligent Physical
Sensors

Intelligent Virtual Sensor
Environment

Historical Data
&
Legacy Sensors

ISHM Implementation for Constellation Systems

- Initial on-board ISHM core capability.

- Cyclic augmentation: From research centers to operational testbeds to flight systems.

- ISHM across multiple Constellation Systems: Based on ISHM in each system