

# IEEE New Orleans Section

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## Intelligent Sensors for Integrated Systems Health Management (ISHM)

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# Outline

- ▣ The Context
- ▣ Integrated Systems Health Management
- ▣ Smart & Intelligent Sensors
- ▣ Why should we care?
- ▣ Conclusions

# NASA Centers



Stennis Space Center, Mississippi

Rocket engine testing at NASA-Stennis is distributed over a 13,500 acre (5,500 ha.) site +120,000 acre (48,500 ha.) noise abatement easement

A-1

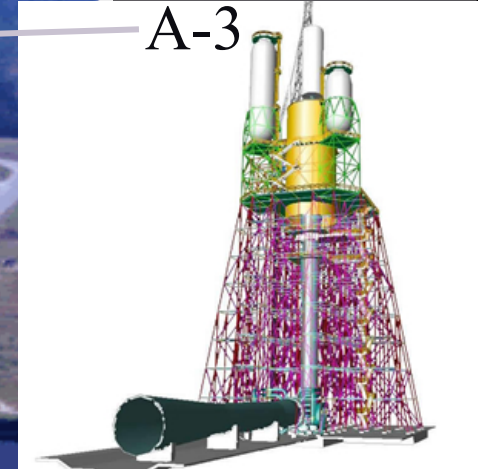


B-1/B-2

A-2



A-3



E-2



E-3



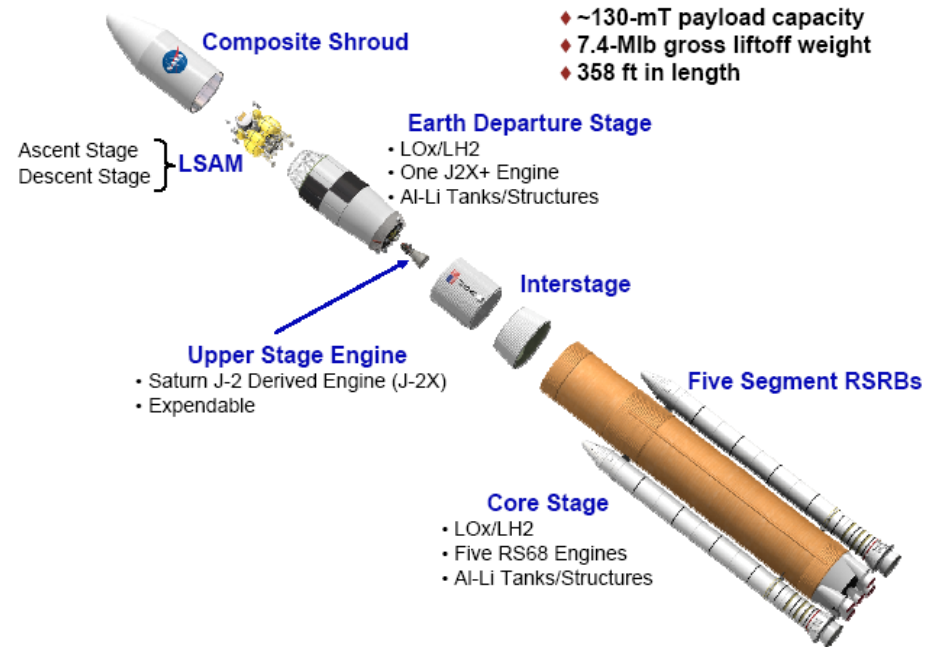
E-1



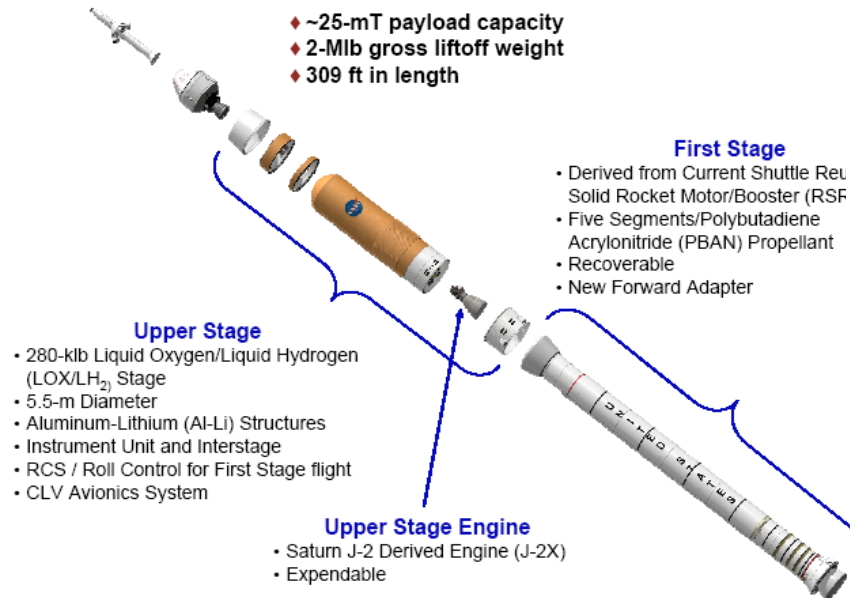


# Constellation: The Next Generation

## Ares V Cargo Launch Vehicle



## Ares I Crew Launch Vehicle



## Ares V: Cargo Launch Vehicle

## Ares I: Crew Launch Vehicle

# Constellation: Return to the Moon

[Constellation.VOB](#)

# Requirements Driving ISHM

- ▣ Improve quality
  - By making better and more reliable measurements
- ▣ Minimize costs
  - Of reconfiguration between test articles
  - Of repair and calibration
- ▣ Avoid downtime
  - By predicting impending failures
  - By timely intervention
- ▣ Increase safety (protect people and assets)

# Technologies and Tools for ISHM

- ▣ ISHM Architecture
- ▣ Health assessment database
- ▣ Anomaly detection methods
- ▣ Predictive modeling
- ▣ Root cause analysis
- ▣ Intelligent elements
- ▣ Integrated awareness



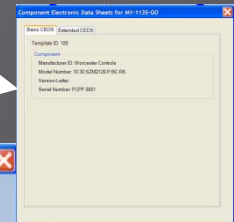
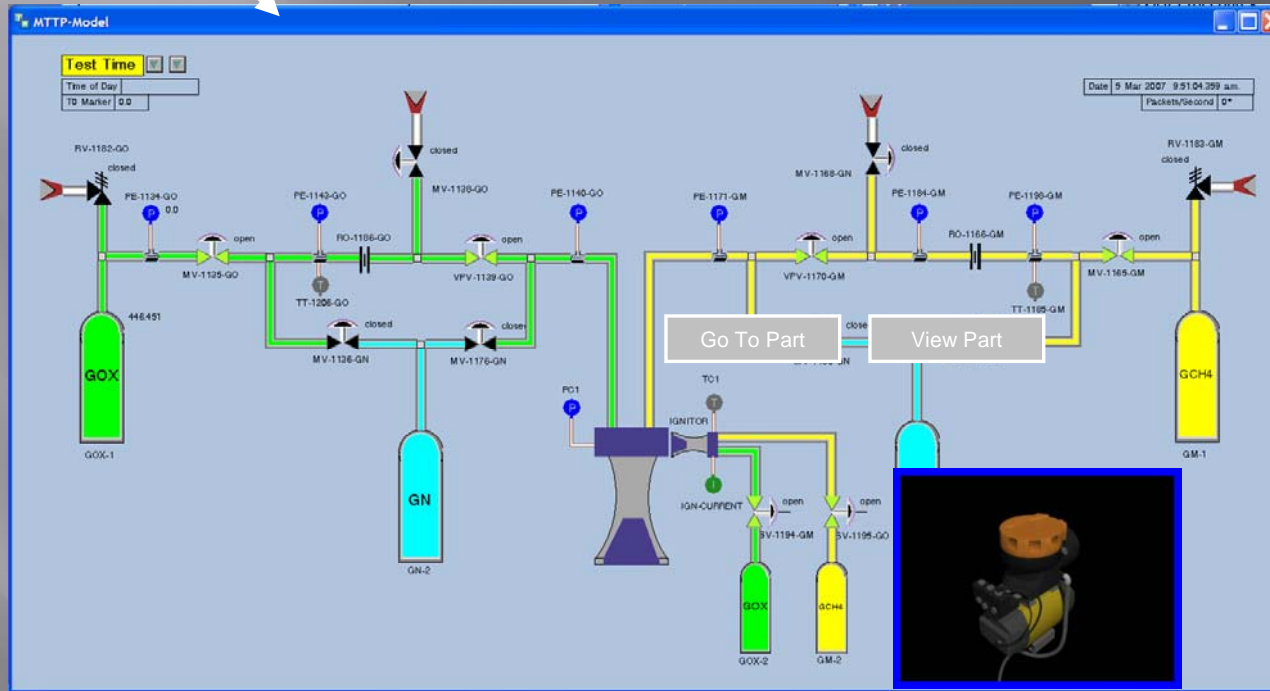
# Component Technology View of an ISHM Application

**ISHM Models (Embedded Data, Information, and Knowledge):**  
MTPP Implementation

**Health Assessment Database:**  
Health Electronic Data Sheets  
Repository of anomalies

**Anomaly Detection:**  
Sensor V&V,  
System pressure  
leaks, etc.

**Smart & Intelligent Sensors**  
Virtual Intelligent  
Sensors

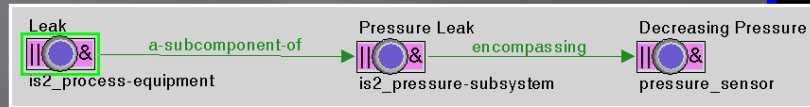


**Integrated Awareness:**  
3-D Health Visualization



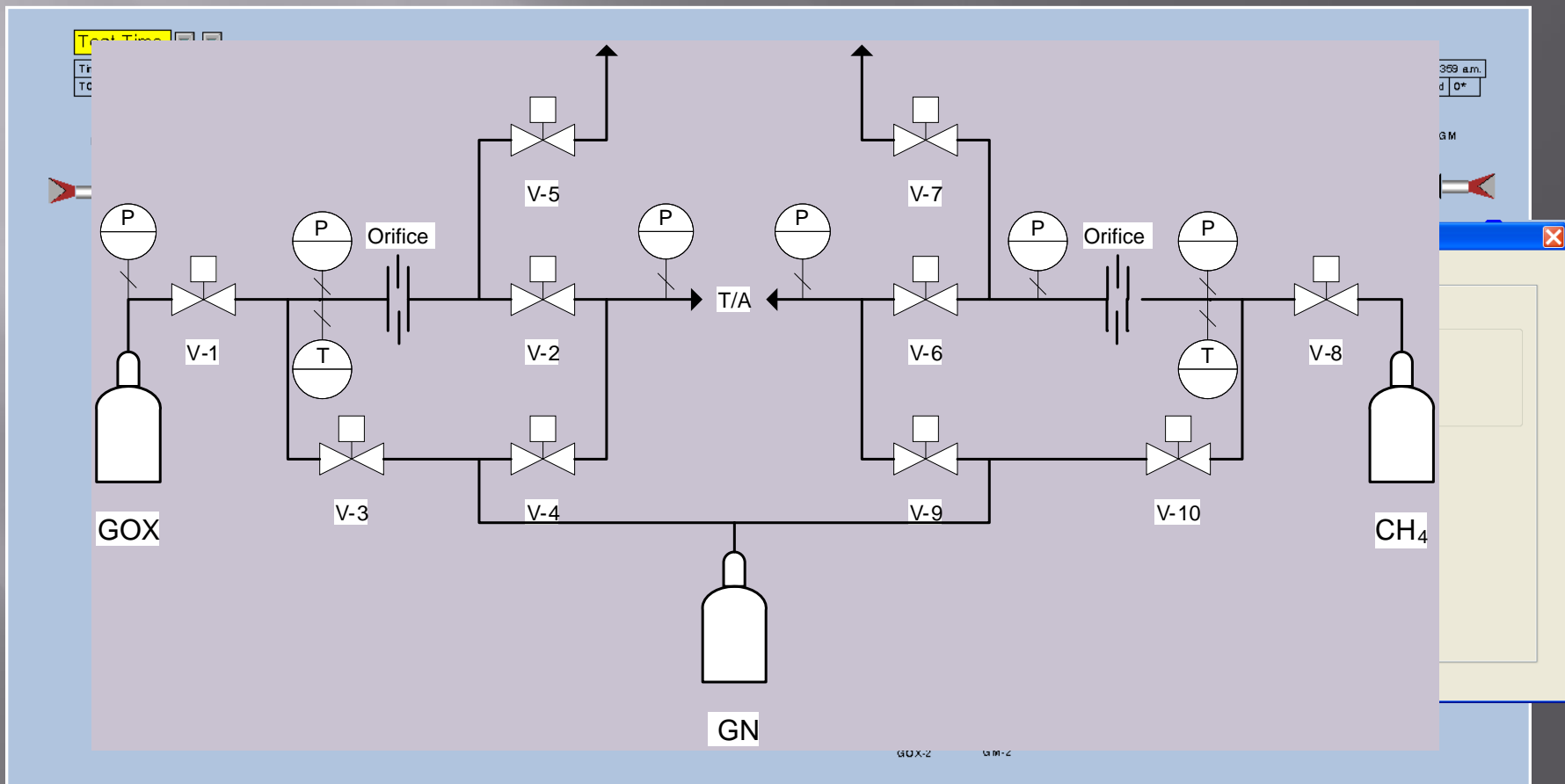
**Embedding of Predictive Models**

**Root Cause Analysis**



# ISHM Enabling Technologies: ISHM Architecture

The Piping and Instrumentation Diagram (P&ID) for a system...



Populated by component objects with associated xEDS...

# ISHM Enabling Technologies: Health Assessment Database

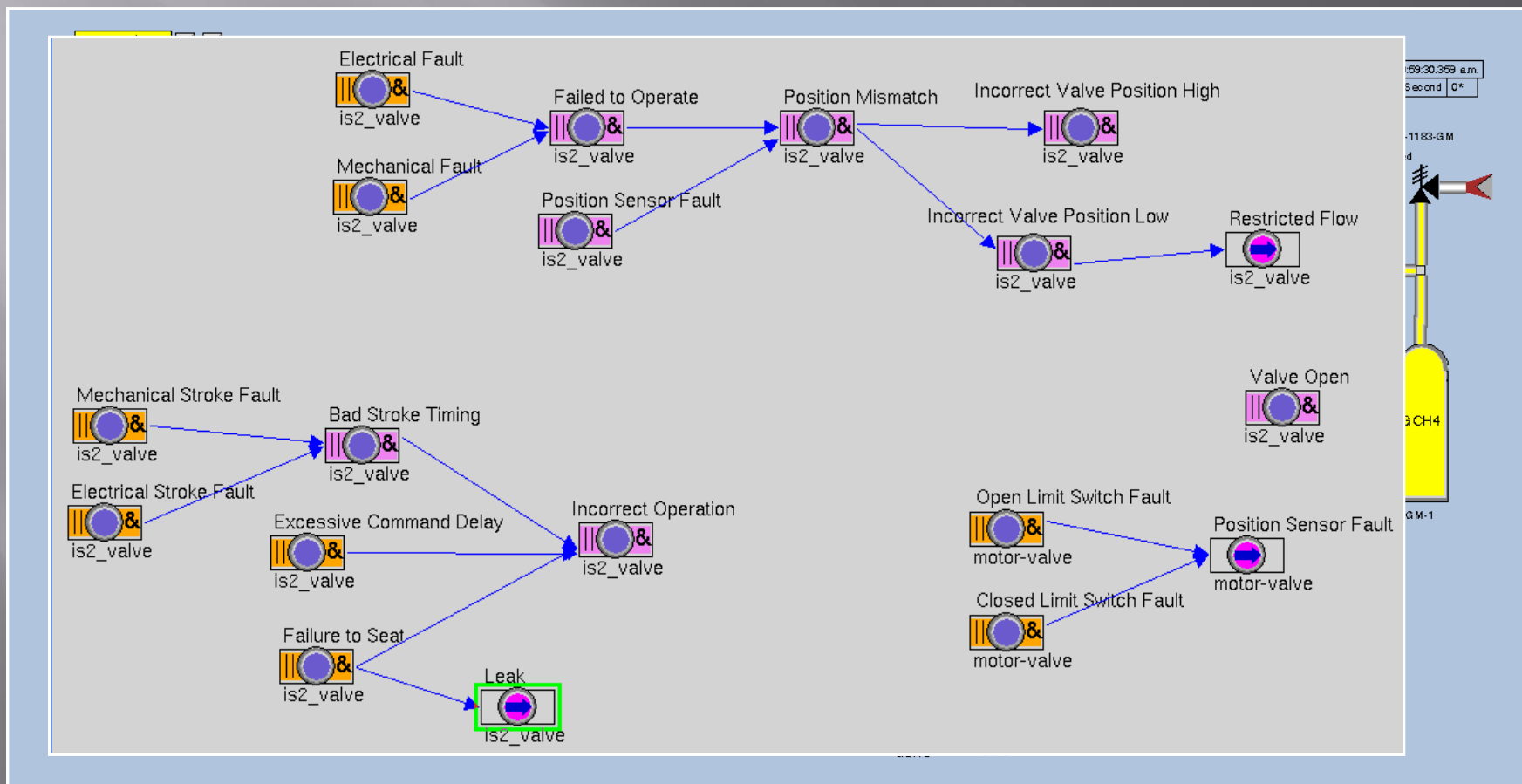
- ▣ Historical data records
  - Nominal
  - Anomalous
- ▣ Algorithm repository
  - Complex for implementation at upper ISHM architecture levels
  - Simplified for embedding in Intelligent Sensor
- ▣ Electronic Data Sheets (EDS)
  - Transducer Electronic Data Sheets (IEEE 1451.4 TEDS)
  - Health Electronic Data Sheet (HEDS)
  - Component EDS (CEDS)
  - Others

# ISHM Enabling Technologies: Anomaly Detection

- ▣ Available w/in NASA (e.g., Glenn Research Center suite developed in the 80's as part of Atlas-Centaur pneumatic and hydraulic system post-flight analysis)
  - Noise Events (Broad spectrum, Impulse)
  - Flat-line Events
  - Level Shift Events
  - Drift Events
- ▣ Standard DSP and Statistics
  - Spectral analysis, Correlation
  - $\sigma$ ,  $\sigma^2$
- ▣ Literature

# ISHM Enabling Technologies: Root Cause Analysis

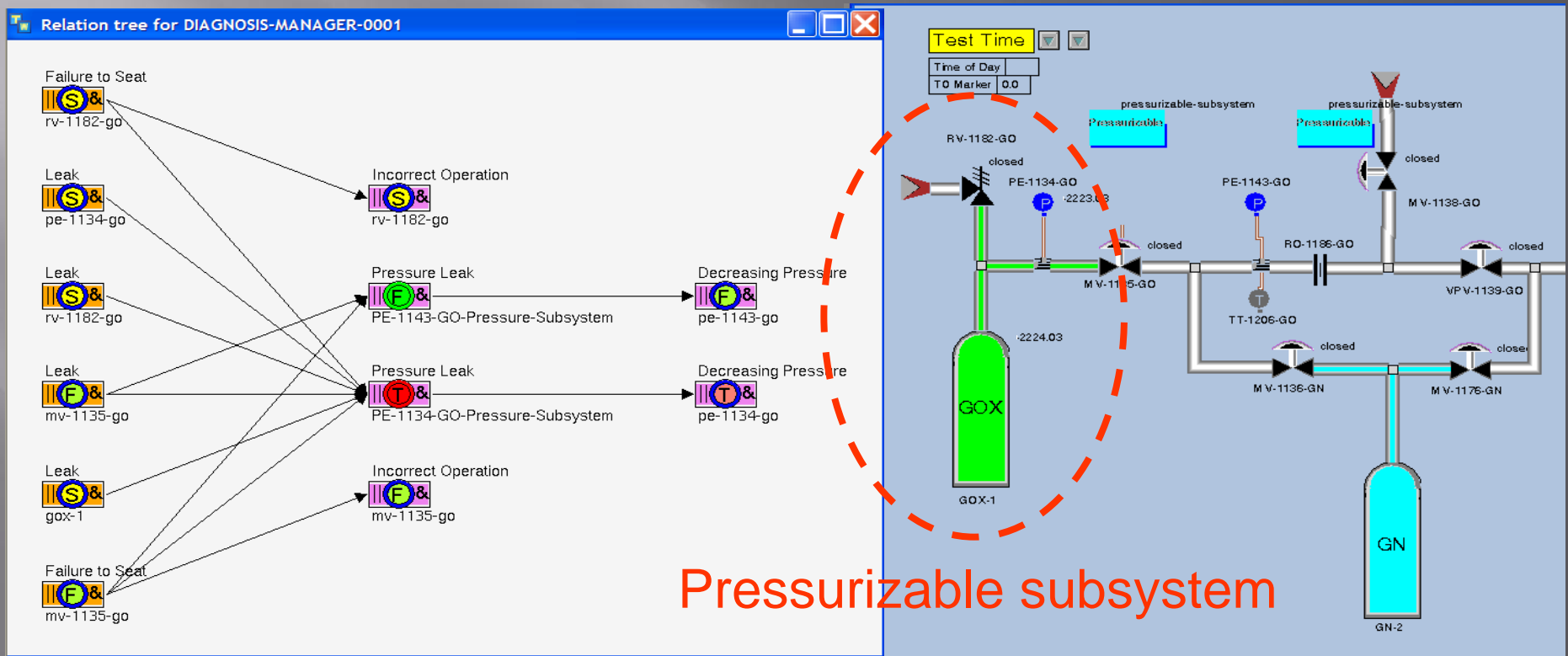
Within the ISHM model is a root cause analysis layer...





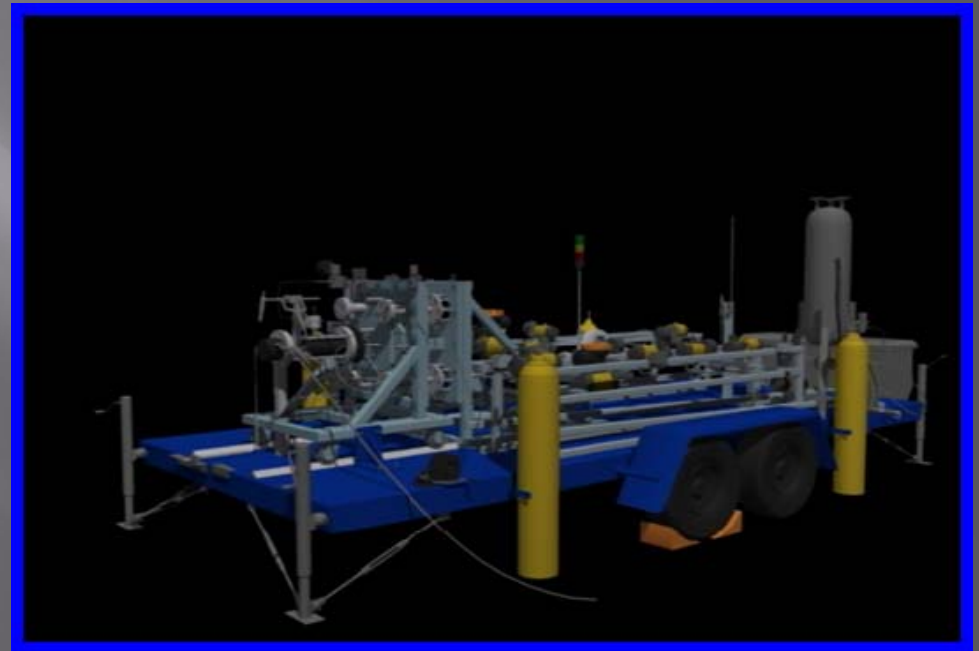
# Example Leak RCA

A decreasing pressure measurement associated with a pressurizable subsystem is used to reason about the possible cause/effects.

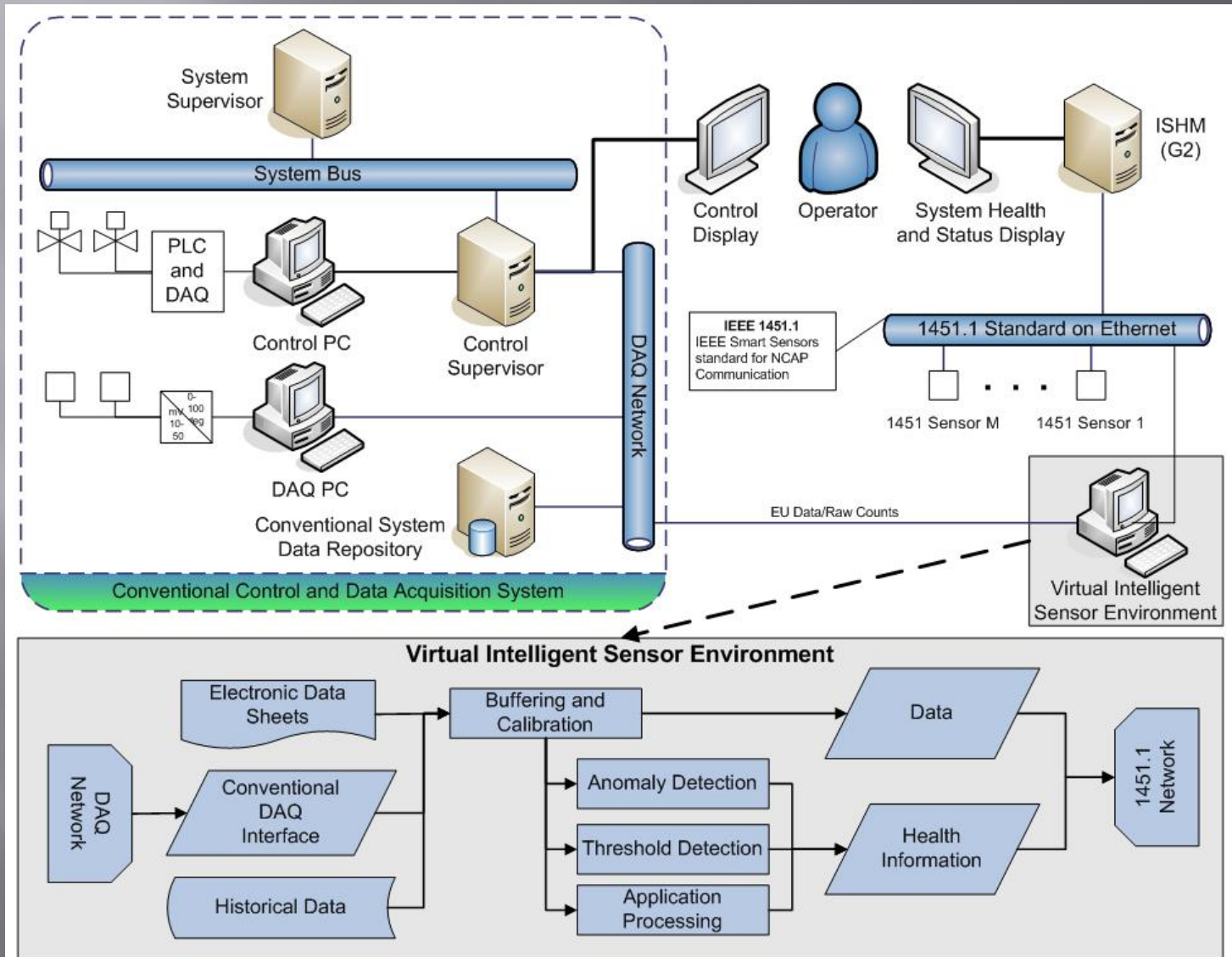


# ISHM Enabling Technologies: Integrated Awareness

- ▣ User interface
  - Minimize information overload
  - Provide navigation through 3d structure
  - Spatial relationships between components
  - Maintenance guide



# Sensors Supporting ISHM



# Smart Sensors

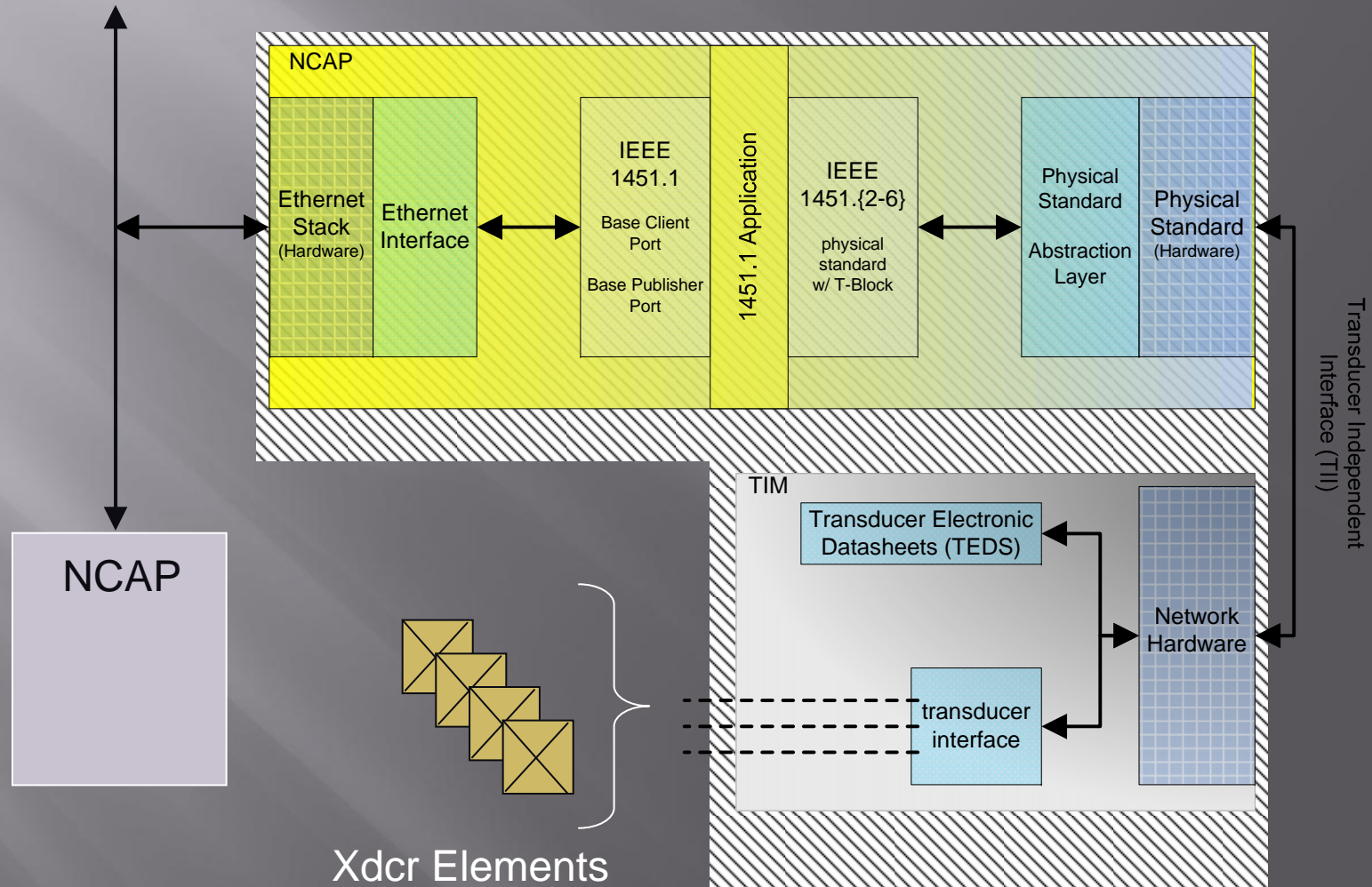
- ▣ A Smart Sensor adheres to one of the IEEE 1451.x Standards; for distributed systems, important to have a network capable application processor (NCAP)
  - IEEE 1451.0 Defines a set of common commands, operations and Transducer Electronic Data Sheets (TEDS) for the family of IEEE 1451 standards
  - IEEE 1451.1 Defines a common object model describing the behavior of a Network Capable Applications Processor (NCAP)

# More IEEE 1451.X Smart Sensor Standards

- IEEE 1451.2 Defines a transducer to NCAP transducer independent interface (TII) and TEDS for a point-to-point configuration of transducer interface modules (TIMs)
- IEEE 1451.3 Defines a transducer to NCAP interface and TEDS for multi-drop transducers
- IEEE 1451.4 Defines a mixed-mode interface for analog transducers with analog and digital operating modes; simplest 1451 model
- IEEE 1451.5 Defines a TII interface and TEDS for wireless transducers
- IEEE P1451.6 Defines a TII interface and TEDS using the controller area network (CAN)
- IEEE P1451.7 Defines an RFID interface



# IEEE 1451 – Smart Sensor Block Diagram



# TEDS

- ▣ The transducer electronic data sheet provides the means to tag a sensor with a description.
  - Manufacturer
  - Serial number
  - Calibration status
  - Coefficients
  - Physical location
- ▣ Offers practical means for reducing costs/errors associated with measurement system configuration

# Definition of an Intelligent Sensor

An *Intelligent Sensor* consists of an *IEEE 1451 Smart Sensor* augmented to support application-specific algorithms and associated electronic data sheets (xEDS) useful to ISHM.

# Making a Smart Sensor Intelligent

- ▣ Capable of embedding algorithms; for example, for ISHM:
  - Noise detection (broadband, bandlimited, spike)
  - Instrumentation anomalies
    - ▣ Flat line
    - ▣ Drift
  - Sensor anomalies
    - ▣ Open/short
    - ▣ Debondment

# Augmenting Core IEEE 1451 Functions

- ▣ NCAP
  - Publish normal data + health
- ▣ Extended TEDS
  - Health electronic data sheet (HEDS)
    - ▣ Set\_HEDS
    - ▣ Get\_HEDS
  - Component electronic data sheet (CEDS)
    - ▣ Set\_CEDS
    - ▣ Get\_CEDS

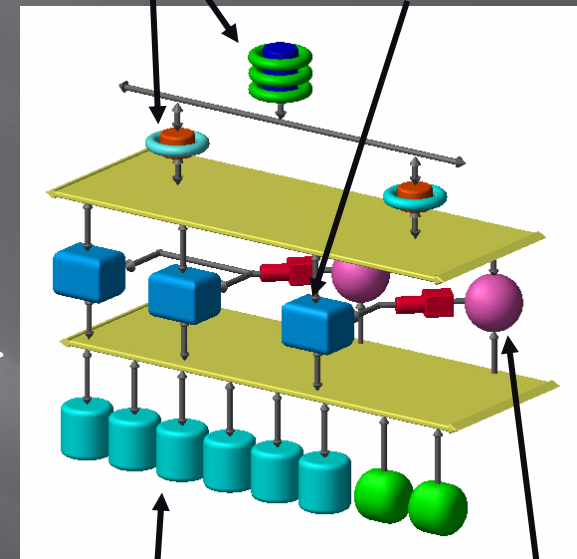


# Intelligent Sensors

- ▣ Smart sensor
  - NCAP (Go Active, Announce)
  - Publish data
  - Set/Get TEDS
- ▣ Intelligent sensor
  - Set/Get HEDS
  - Publish health
- ▣ Detect classes of anomalies using:
  - Using statistical measures
    - ▣ Mean
    - ▣ Standard deviation
    - ▣ RMS
  - Polynomial fits
  - Derivatives (1<sup>st</sup>, 2<sup>nd</sup>)
  - Filtering – e.g., Butterworth HP
  - FFT – e.g., 64-point
  - Algorithms for
    - Flat
    - Impulsive (“spike”) noise
    - White noise
  - Other (ANN, etc.)

Intelligent (Sub)Systems

Intelligent Processes



Intelligent Actuators

Intelligent Sensors

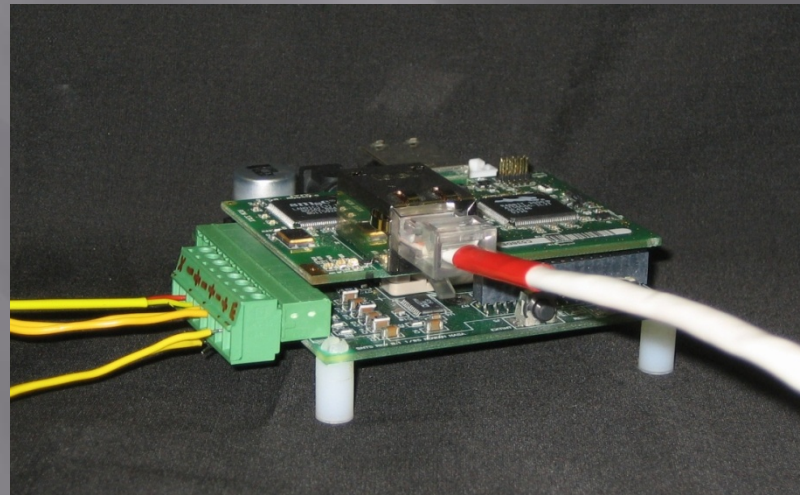
# Example ISHM-Enabled Intelligent Sensors

## Hardware

- 3-Ch Thermocouple
- 24-bit ADC
- 8-bit  $\mu$ P
- 1 MB RAM/Flash
- SPI
- Ethernet (802.3af)

## IEEE 1451

- NCAPBlock\_Go\_Active
- NCAP\_Block\_Go\_InActive
- Request\_NCAPBlock\_Announcement
- NCAPBlock\_Announcement
- PublishNormalData



## ISHM

- Mean, Std dev, Min/Max, RMS
- $dv/dx$ ,  $d^2v/dx^2$
- Poly fit
- Bu HPF (13<sup>th</sup>)
- 64-pt FFT
- Anomalies: Flat, Spike, Noise

- PublishNormalData+Health
- Channel\_Sample\_Rate
- Get\_HEDS •Set\_HEDS •Get\_TEDS •Set\_TEDS

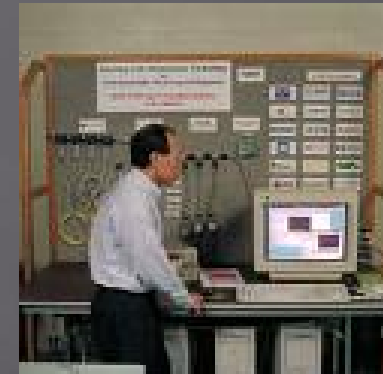
# Other Smart Sensors—Some w/ Intelligent Sensor Capabilities



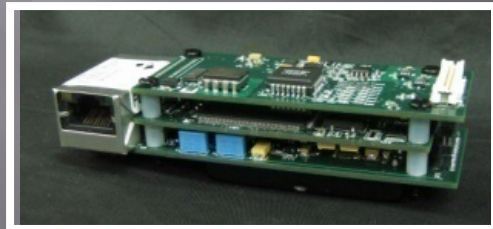
Mobitrum  
[www.mobitrum.com](http://www.mobitrum.com)



Smart Sensor Systems  
[www.smartsensorsystems.com](http://www.smartsensorsystems.com)



NIST  
[www.mel.nist.com](http://www.mel.nist.com)



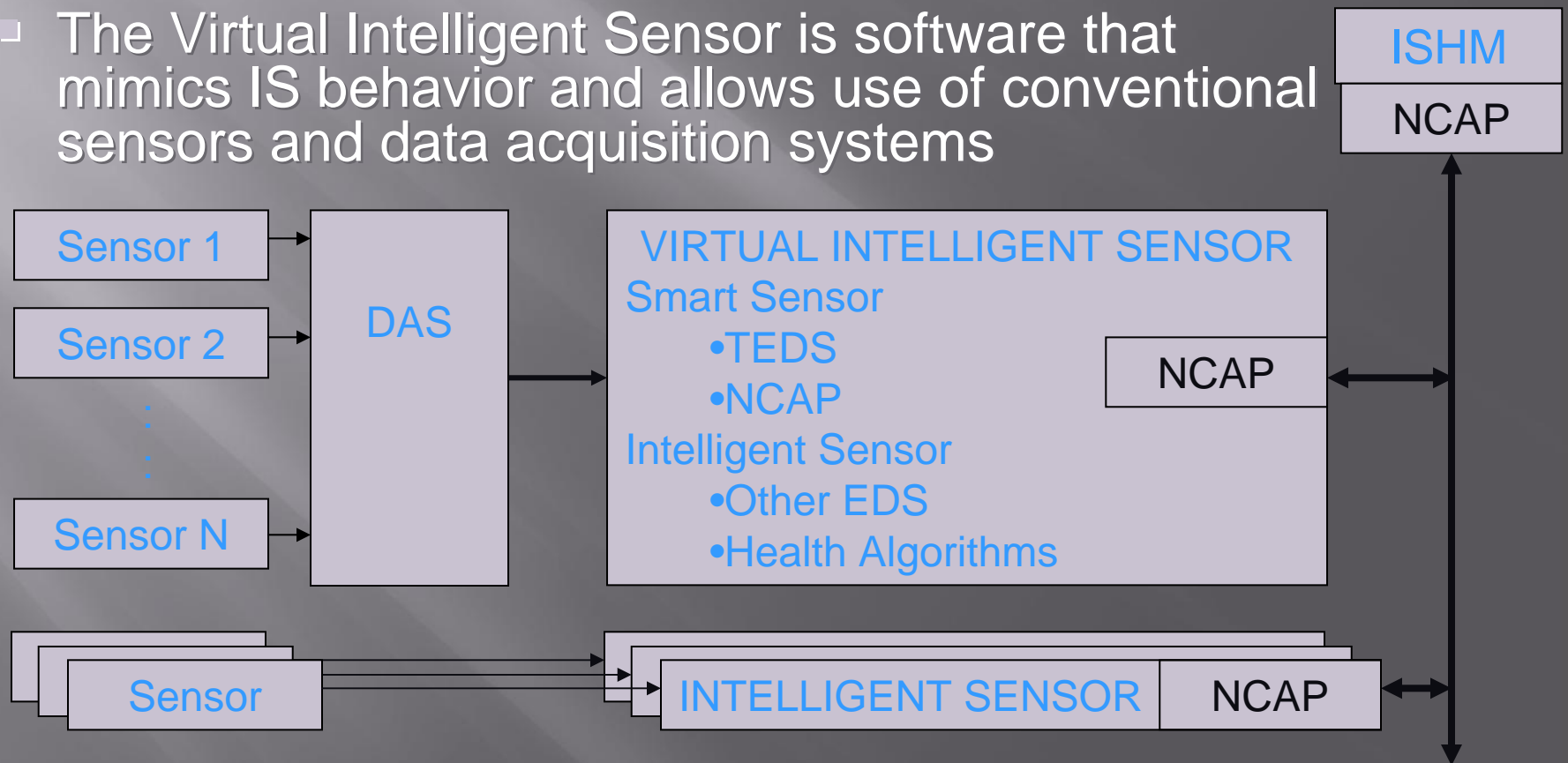
KSC - SNE



Eensors  
[www.eesensors.com](http://www.eesensors.com)

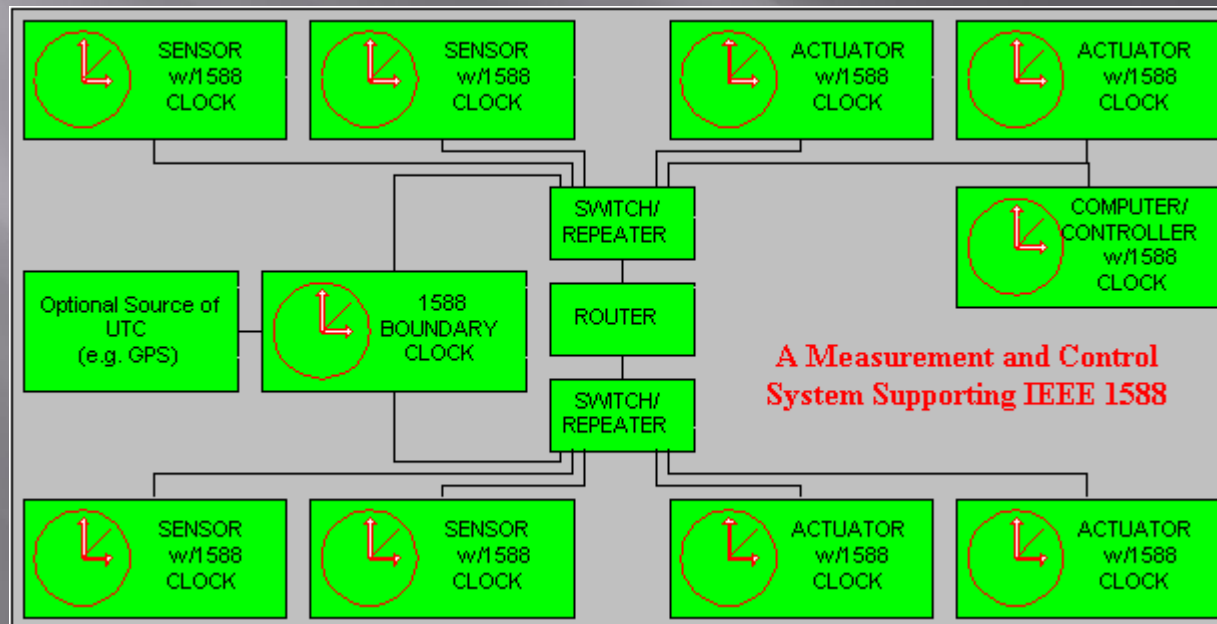
# ISHM Enabling Technologies: Intelligent Sensors

- Unfortunately, Intelligent Sensors are not widely available; to realize IS benefits in a system populated with conventional sensors, create a Virtual IS
- The Virtual Intelligent Sensor is software that mimics IS behavior and allows use of conventional sensors and data acquisition systems



# Other Issues: Timing in Sensor Networks

- Need to provide time synchronization across multiple IS nodes in order to time-align measurements
- IEEE-1588 in distributed networks
  - For spatially-localized networks (e.g., Test stand, Space vehicle, Labs)
  - $\mu\text{s}$  to sub- $\mu\text{s}$  accuracy
  - Local oscillators synchronized to Grand Master Clock by measuring network transport delays





# Why Should We Care?

- ▣ Sensors are ubiquitous
- ▣ Pressure for increased efficiency, etc.
- ▣ Systems view
- ▣ MEMS + Nanotechnology + Solid-State
- ▣ Distributed reasoning
- ▣ Plug-and-Play

# Conclusions

- ▣ IEEE 1451 Smart Sensors contribute to a number of ISHM goals including cost reduction achieved through
  - Improved configuration management (TEDS)
  - Plug-and-play re-configuration
- ▣ Intelligent Sensors are adaptation of Smart Sensors to include ISHM algorithms; this offers further benefits
  - Sensor validation
  - Confidence assessment of measurement
  - Distributed ISHM processing
- ▣ Space-qualified intelligent sensors are possible
  - Size, mass, power constraints
  - Bus structure/protocol

Lunar Habitat



# Discussion

