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

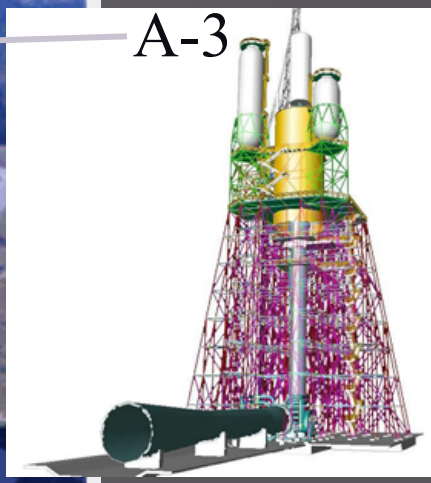
Rocket engine testing at NASA-Stennis is distributed over a 13,500 acre (5,500 ha.) site +120,000 acre (48,500 ha.) noise abatement easement

B-1/B-2

A-1

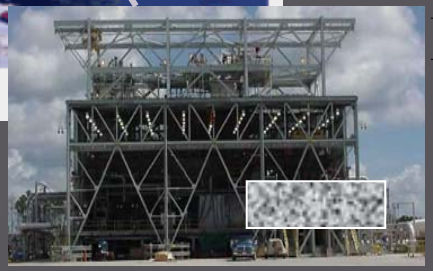
A-2

A-3



E-2

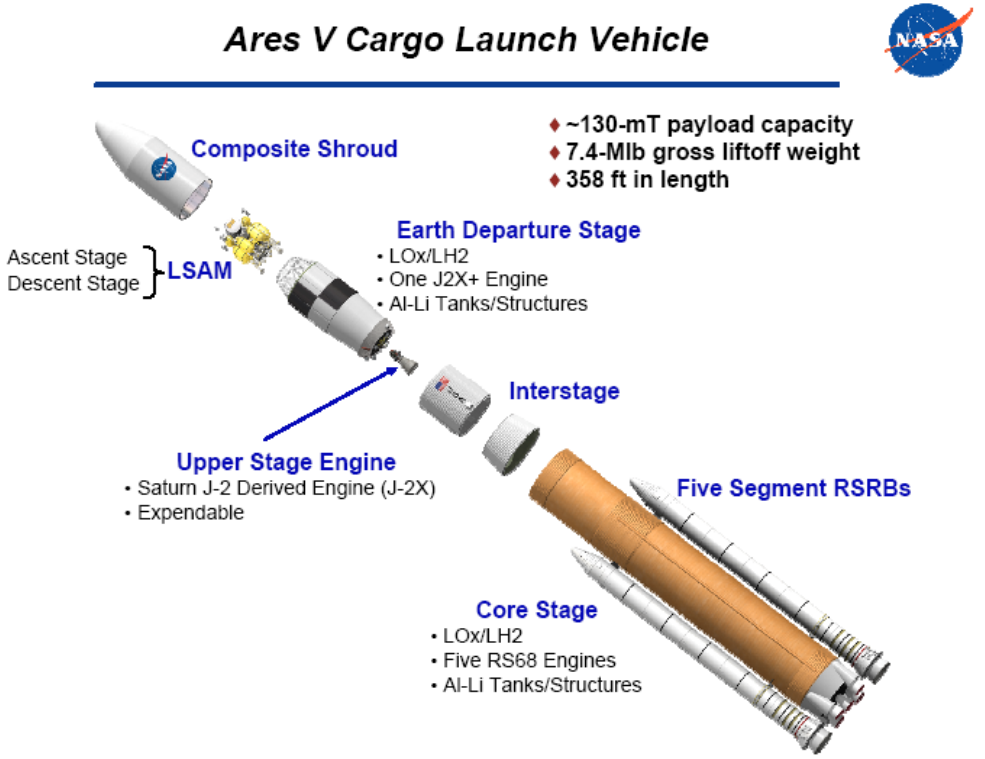
E-3



E-1

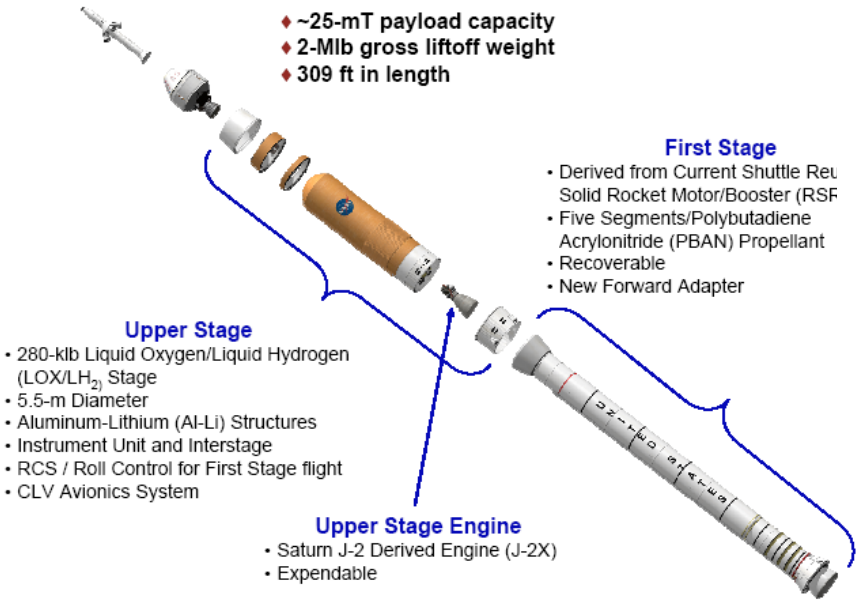
Constellation: The Next Generation

Ares V Cargo Launch Vehicle



Ares V: Cargo Launch Vehicle

Ares I Crew 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)

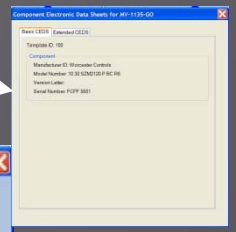
Technologies and Tools for ISHM

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

Component Technology View of an ISHM Application

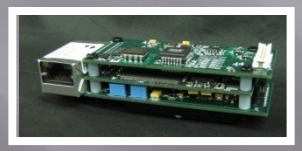
ISHM Models (Embedded Data, Information, and Knowledge):
MTTP Implementation

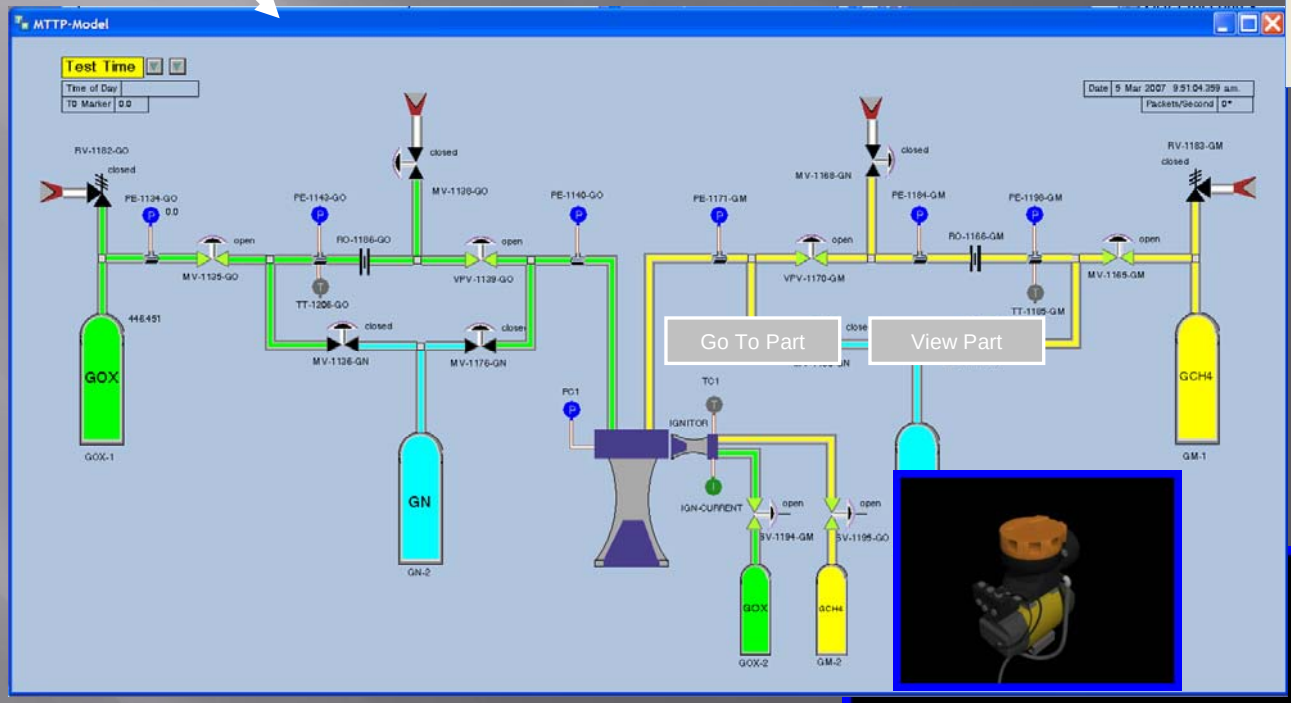
Health Assessment Database:
Health Electronic Data Sheets
Repository of anomalies



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

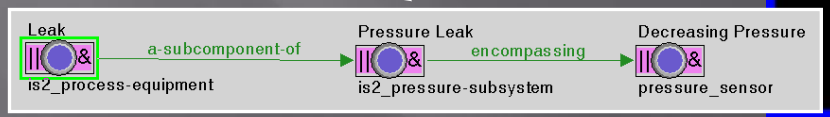
Smart & Intelligent Sensors
Virtual Intelligent Sensors





Integrated Awareness:
3-D Health Visualization

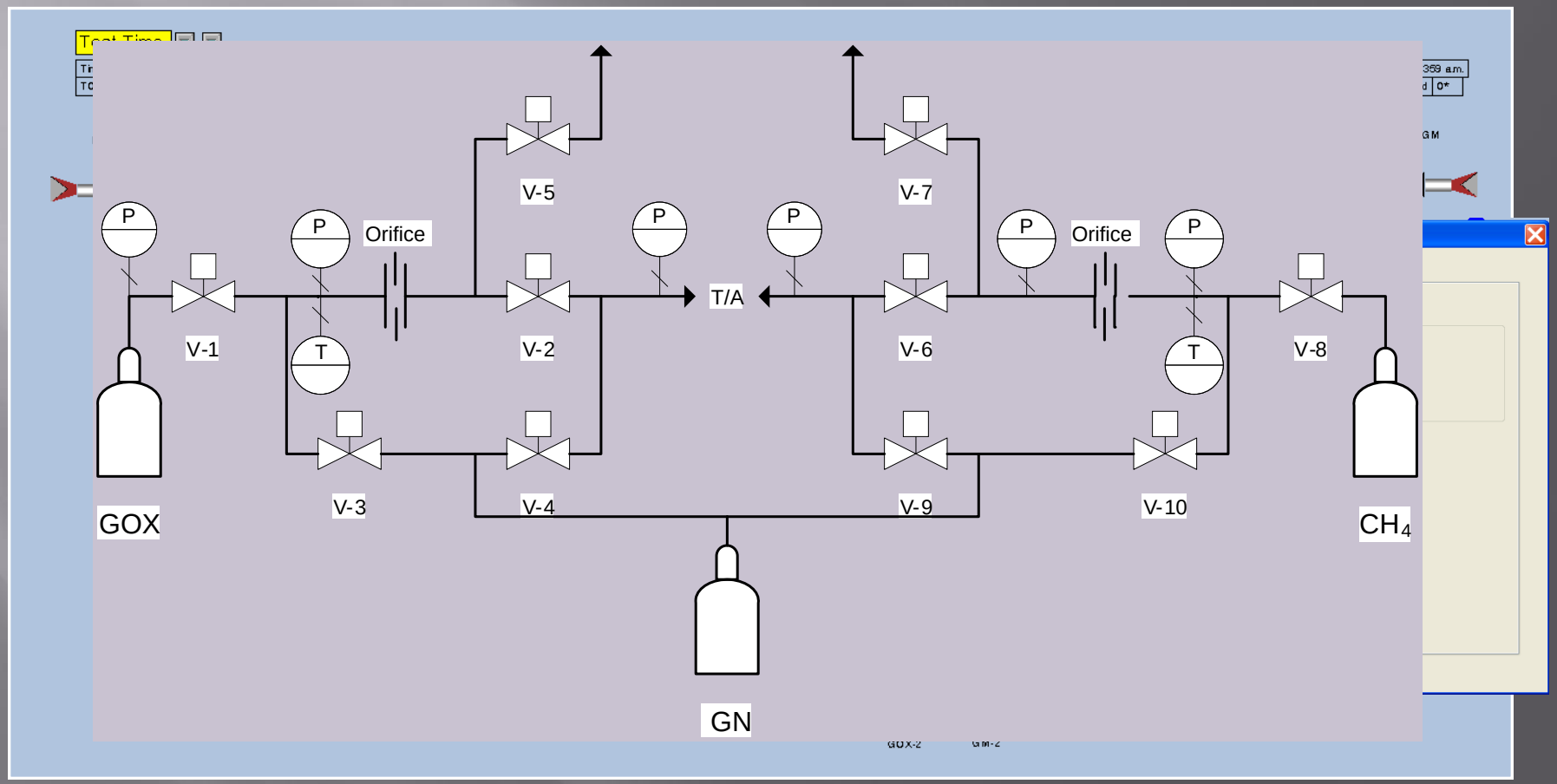
Root Cause Analysis



Embedding of Predictive Models

ISHM Enabling Technologies: ISHM Architecture

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



Populated by component objects with associated xEDS…

ISHM Enabling Technologies: Health Assessment Database

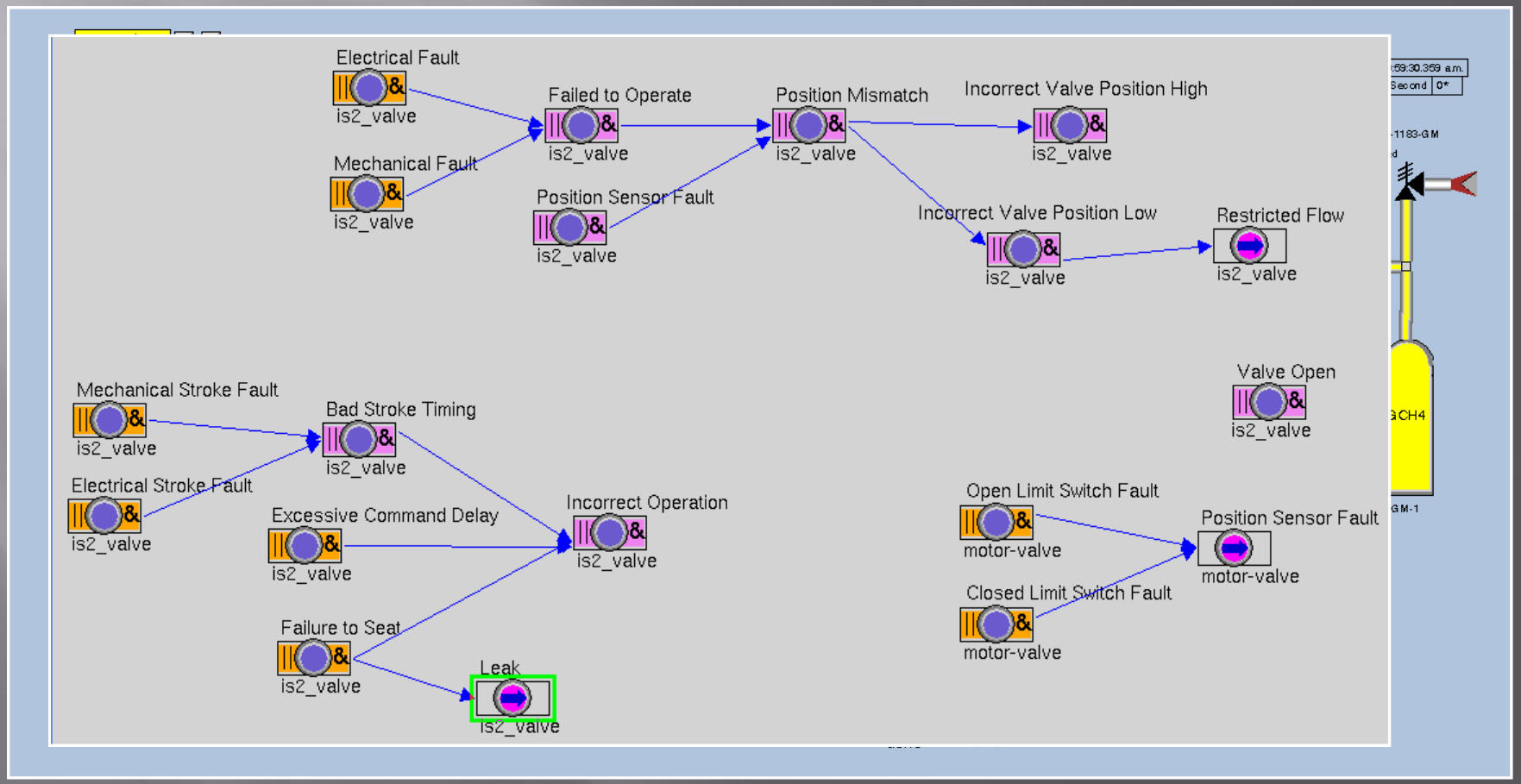
- Historical data records
  - Nominal
  - Anomalous
- Algorithm repository
  - Complex for implementation at upper ISHM architecture levels
  - Simplified for embedding in Intelligent Sensor
- Electronic Data Sheets (EDS)
  - Transducer Electronic Data Sheets (IEEE 1451.4 TEDS)
  - Health Electronic 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
  - σ, σ^2
- Literature

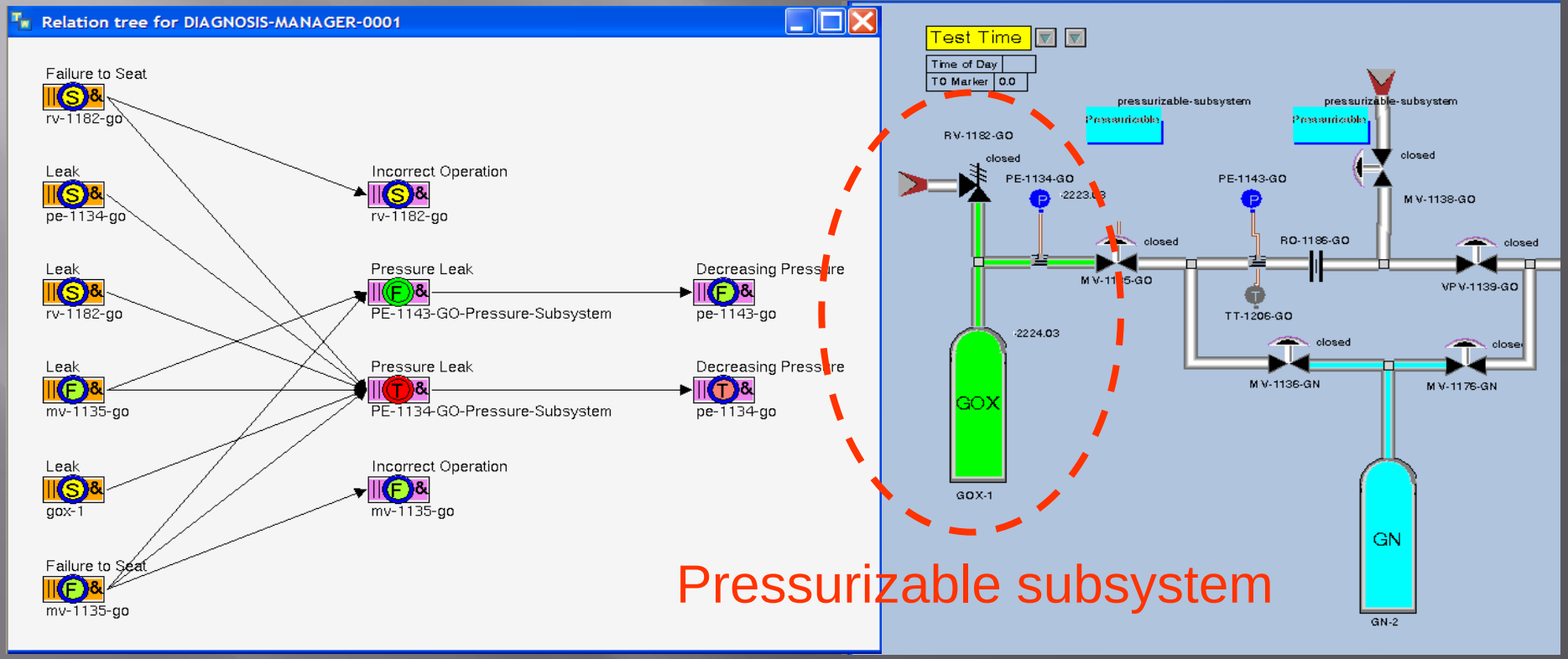
ISHM Enabling Technologies: Root Cause Analysis

Within the ISHM model is a root cause analysis layer…
That describes cause/effect relationships…



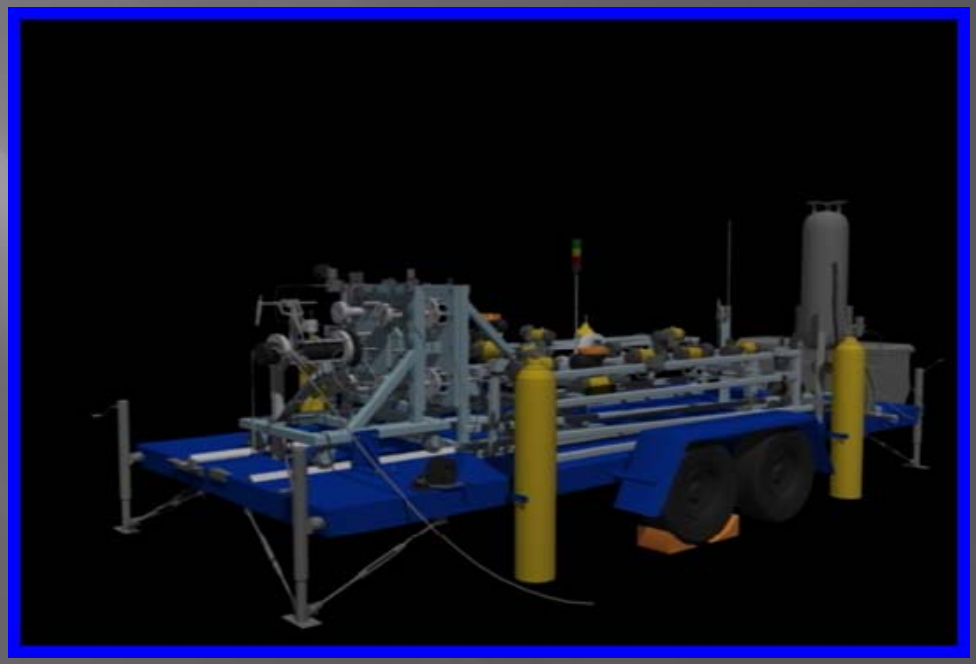
Example Leak RCA

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

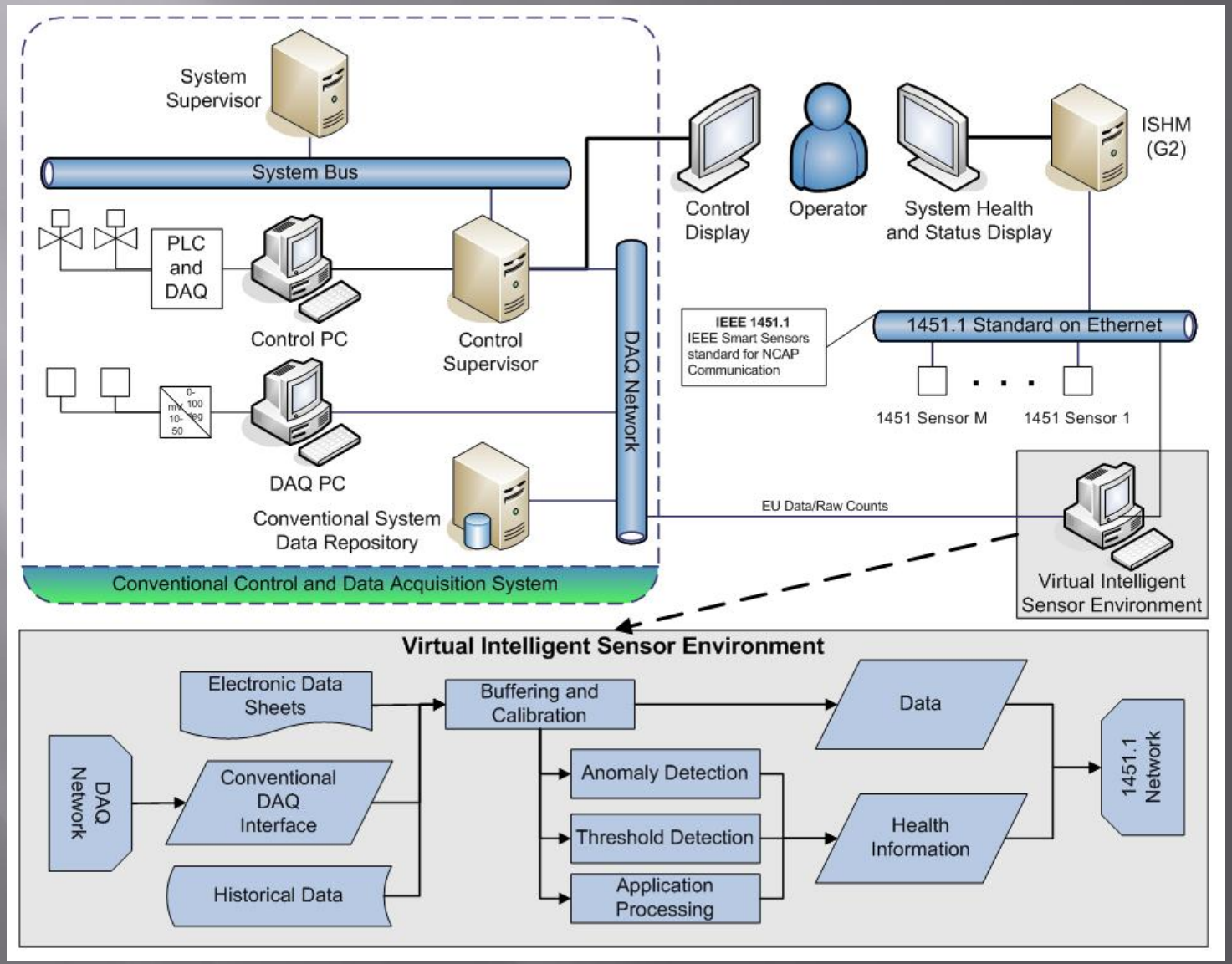


ISHM Enabling Technologies: Integrated Awareness

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



Sensors Supporting ISHM



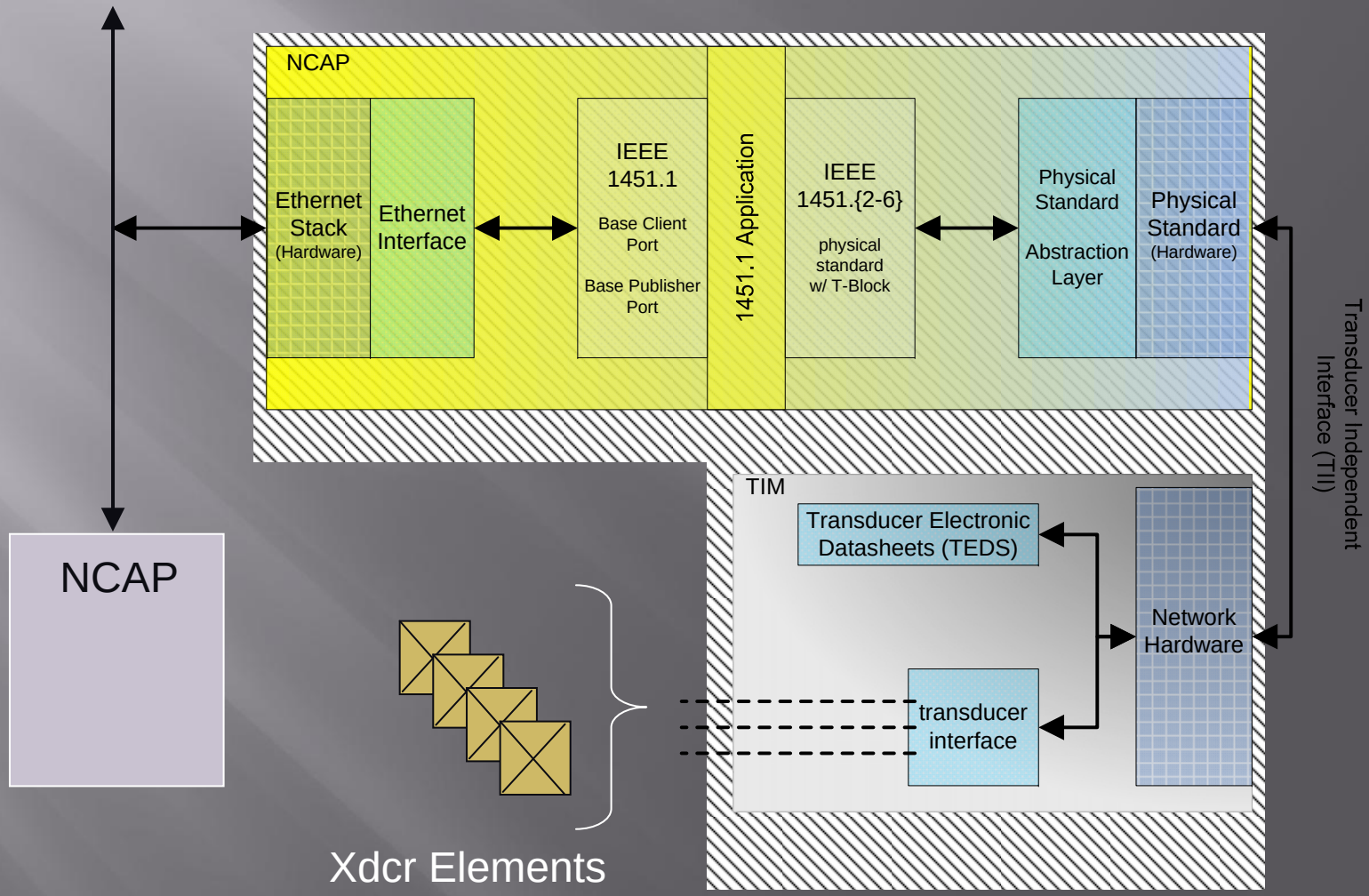
Smart Sensors

- 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

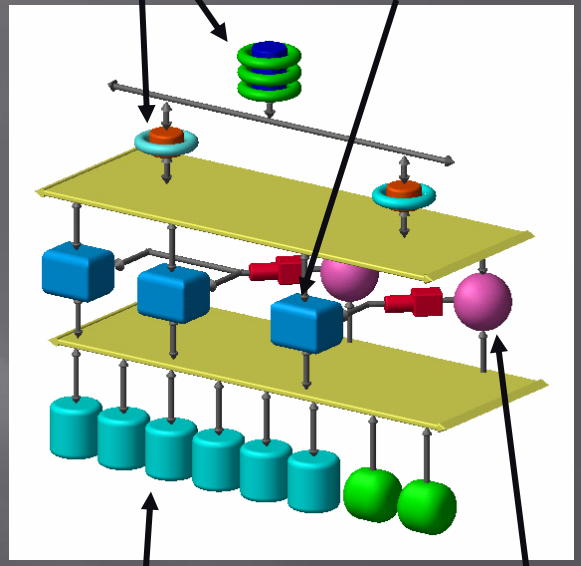
- Capable of embedding algorithms; for example, for ISHM:
  - Noise detection (broadband, bandlimited, spike)
  - Instrumentation anomalies
    - Flat line
    - Drift
  - Sensor anomalies
    - Open/short
    - Debondment

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 (1st, 2nd)
  - Filtering—e.g., Butterworth HP
  - FFT—e.g., 64-point
  - Algorithms for
    - Flat
    - Impulsive ("spike") noise
    - White noise
  - Other (ANN, etc.)



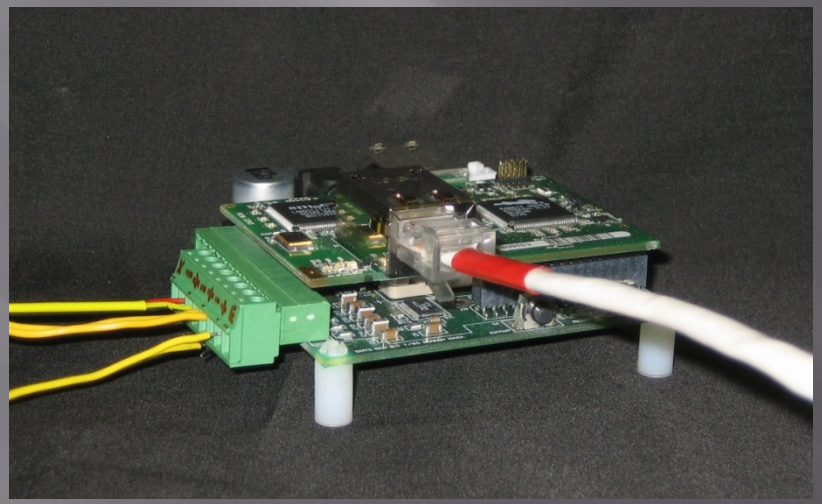
Example ISHM-Enabled Intelligent Sensors

Hardware

- 3-Ch Thermocouple
- 24-bit ADC
- 8-bit µP
- 1 MB RAM/Flash
- SPI
- Ethernet (802.3af)

IEEE 1451

- NCAPBlock_Go_Active
- NCAP_Block_Go_InActive
- Request_NCAPBlock_Announcement
- NCAPBlock_Announcement
- PublishNormalData



- PublishNormalData+Health
- Channel_Sample_Rate
- Get_HEDS •Set_HEDS •Get_TEDS •Set_TEDS

ISHM

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

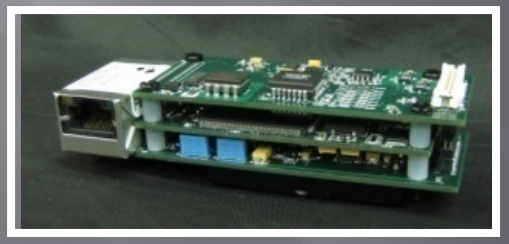
Rowan University

Other Smart Sensors—Some w/ Intelligent Sensor Capabilities

Mobitrum
www.mobitrum.com

Smart Sensor Systems
www.smartsensorsystems.com

NIST
www.mel.nist.com

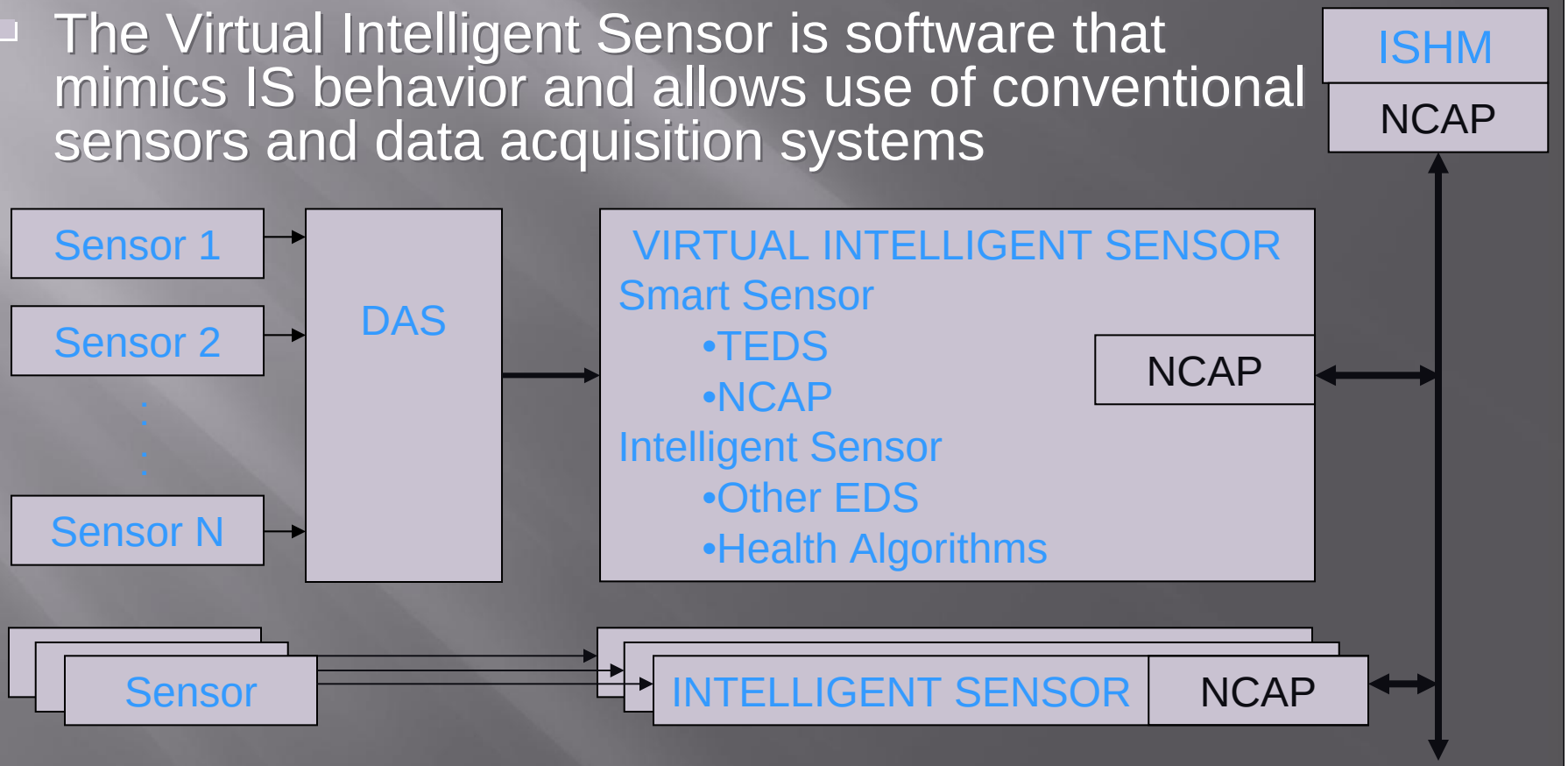


KSC - SNE

Esensors
www.eesensors.com

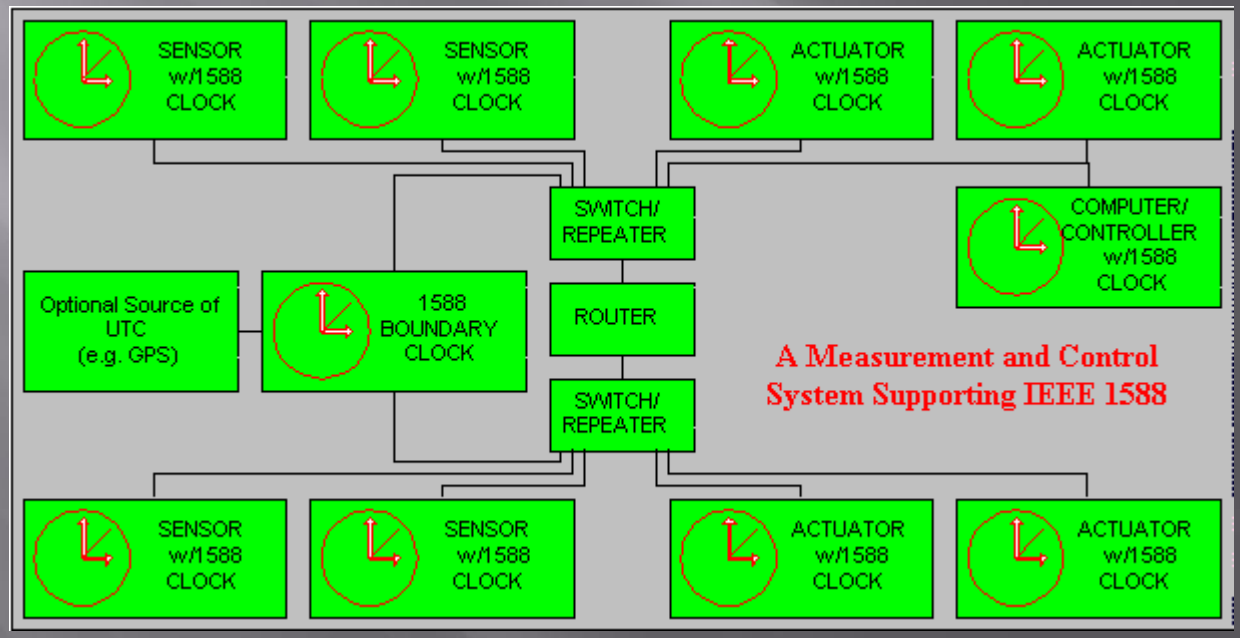
ISHM Enabling Technologies: Intelligent Sensors

- 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)
  - μs to sub-μs accuracy
  - Local oscillators synchronized to Grand Master Clock by measuring network transport delays



http://ieee1588.nist.gov/

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