Title: A Framework for Intelligent Rocket Test Facilities with Smart Sensor Elements

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Introduction

A long-term center goal at the John C. Stennis Space Center (SSC) is the formulation and implementation of a framework for an Intelligent Rocket Test Facility (IRTF), which incorporates distributed smart sensor elements. The IRTF is to provide reliable, high-confidence measurements. Specific objectives include: (1) Definition of a framework and architecture that supports implementation of highly autonomous methodologies founded on basic physical principles and embedded knowledge. (2) Modeling of autonomous sensors and processes as self-sufficient, evolutionary elements. (3) Development of appropriate communications protocols to enable the complex interactions that must take place to allow timely and high-quality flow of information among all the autonomous elements of the system. (4) Development of lab-scale prototypes of key system elements. Though our application is next-generation rocket test facilities, applications for the approach are much wider and include monitoring of shuttle launch operations, air and spacecraft operations and health monitoring, and other large-scale industrial system operations such as found in processing and manufacturing plants.

Elements of a prototype IRTF have been implemented in preparation for advanced development and validation using rocket test stand facilities at SSC. This work has identified issues that are important to further development of complex networks and should be of interest to others working with sensor networks.

Preliminaries

There is a rapid evolution of aerospace systems to complex, multi-agent structures. At the same time, there is increased emphasis on achieving higher safety, quality, and better price-performance. NASA's John C. Stennis Space Center mirrors these developments and has been actively pursuing ways to manage the complexity and improve the quality and cost of testing rocket engines. Engine test articles range from the Space Shuttle Main Engine (SSME) to the expanding range of engine development programs for future space flight. Using rocket engine testing as the development model for autonomous systems makes sense for two reasons: (1) Rocket test facilities are essentially complete propulsion systems; even when testing only components, the test facility assumes the role of missing engine subsystems. Developing autonomous systems in support of ground-based testing will have direct application to flight propulsion systems [1]. (2) Stennis Space Center is focused on delivering the highest-quality data to its propulsion test customers. Data must be accurate and have the high integrity, while maintaining safe operation and providing timely services at reasonable costs. Autonomous system development that improves quality of data while improving safety and cost-effectiveness will also have direct application to a wide spectrum of aerospace applications. In addition, such techniques are important to a broad range of commercial interests such as nondestructive testing, power generation, manufacturing, military applications, chemical plants, transportation systems, etc.

Fig. 1 depicts the overall architecture concept. Networks of elements with autonomous character cooperate to perform as a *system* composed of a collection of *processes*, each managing a collection of *sensors*, actuators, and other components. Fig. 2 further elaborates on the model emphasizing the knowledge bases that support each element of the hierarchy and the relationships between them. A key feature of the IRTF is the evaluation of *condition* for all elements performed both autonomously and using feedback from other higher-order elements.

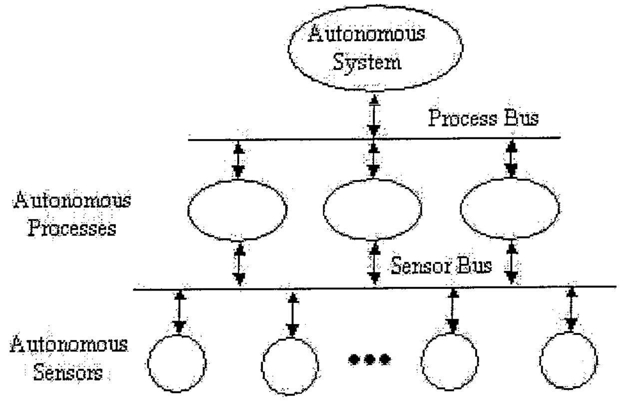


Fig 1. Autonomous system architecture.

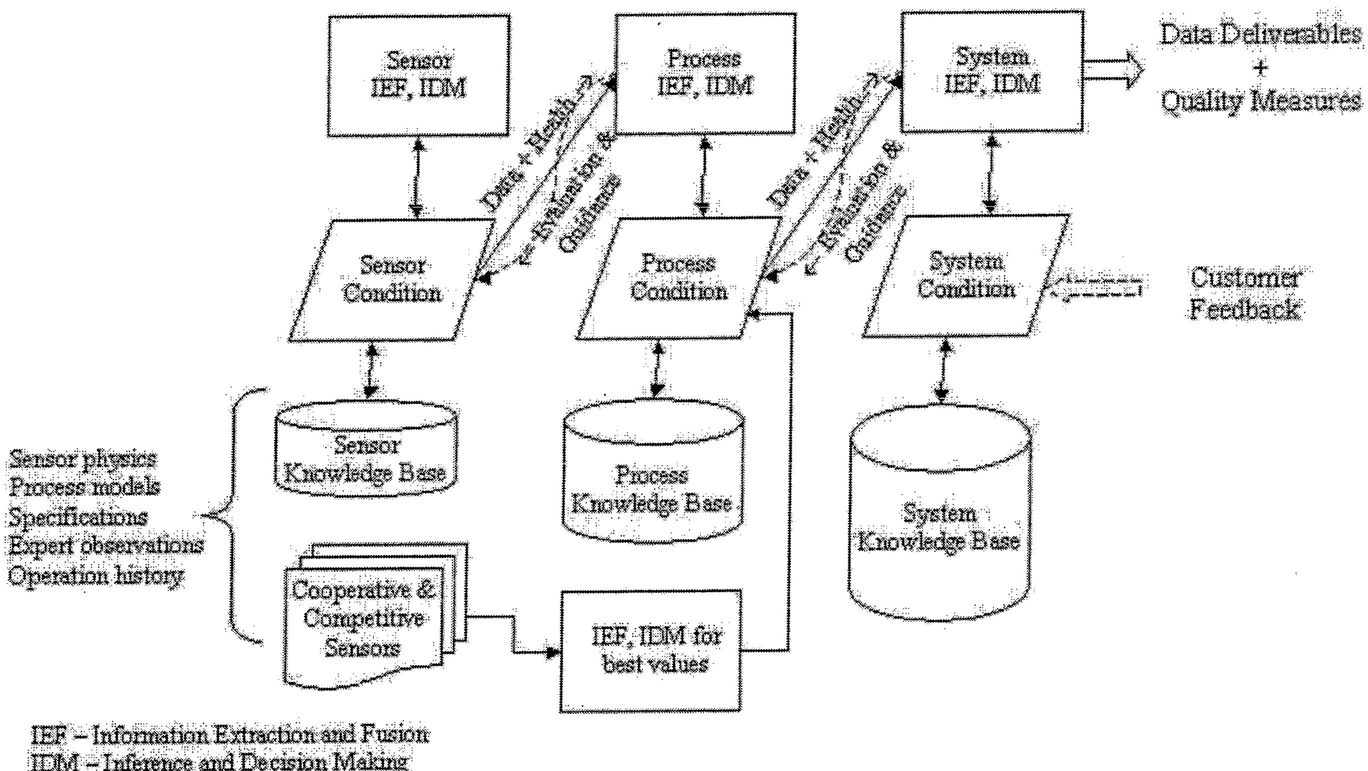
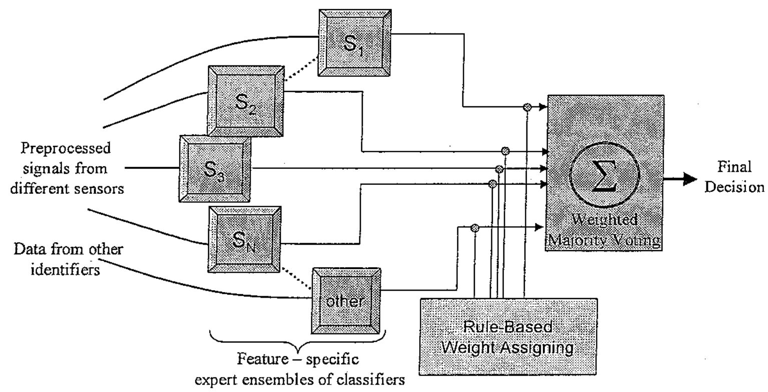


Fig. 2. Model of distributed autonomous system for propulsion testing.

Relationship to the prior art. This work builds on the work of a number of other investigators working in related areas. Much work has been undertaken to develop standards for smart sensor communication such as IEEE 1451 [2]; Lee [3] describes the nature of the sensor interface standards. In our work, we have adopted the IEEE 1451 model of network-capable application processor (NCAP) and have included the transducer electronic data sheet (TEDS). In addition, we are interested in adding health-related information to the sensor. This health electronic data sheet (HEDS) would be analogous to and an extension of TEDS. Similarly, other investigators have reported on developing smart sensors and sensor interfaces. For example, Paschalidis [4], Hogenbirk, et al. [5], and Ferrari, et al. [6], describe development of smart sensors. In particular, these and other reported smart sensors use a variety of common communication protocols such as I^2C, SPI, and Internet-based communication. We have adopted all of these in our prototype development system in order to provide maximum development and test flexibility.

Others have investigated frameworks for smart sensor and intelligent systems. For example, Cheng-He, et al. [7] working in the area of sensor fusion in robotic networks developed an approach emphasizing communication between sensors to avoid high communication requirements with a central fusion center. In our current approach, the IRTF is modeled as a rigorous hierarchy to postpone the issues of inter-sensor communication to a later date. However, we can adopt their schema of smart sensor attributes including prediction, planning, updating, communication, and assimilation. In fact, sensor fusion is one area that we have identified as a core IRTF technology. This is because collections of sensors must be logically combined together into processes, which involves fusing data from a potentially large number of sensors. Sensor fusion is of interest to a variety of application areas including robotics as described by Luo and Kay [8] and novel adaptive data fusion algorithms as developed by Polikar [9] and illustrated in Fig. 3.

Fig. 3. Conceptual Model of Learn++.



Results

Our investigational work employs G2 software [10], which is designed to handle complex intelligent systems. We are using G2 since it allows development of layered system behaviors analogous to the hierarchical autonomous architecture we seek to develop. Development to date (07/2003) has accomplished the following tasks:

- Developed the skeleton G2 framework that can integrate system, processes, and sensors.
- Developed the G2 gateway services that support interfaces with Internet-based sensors, files, and other application programs such as MatLab [11].
- Developed core smart sensors based on an Ethernet core microcontroller [12] with interfaces for I^2C, SPI, RS-232, and iButtons [13] to support a spectrum of sensor types and features. Sensors include NCAP and TEDS functionality.

Next steps

With the framework outline completed and core elements instantiated; current efforts address the following task areas, which will provide depth and breadth to the IRTF functions. Results in these areas will be reported as they are developed.

- Define knowledge bases appropriate for the three core elements of the architecture. This includes incorporating component specifications, behavioral models (analytic, empirical, qualitative, etc.), test requirements, expert observations, facility operation history, and other items. Develop techniques for using and updating the knowledge bases.
- Define condition states for all elements and methods for performing the associated information extraction and fusion (IEF) and the associated inferencing and decision making (IDM).
- Refine smart sensor architectures to include diagnostic agents and communication protocols that allow embedding health information and the exchange of health assessment data.

- Develop a physical test bed that includes key facility components to allow validating the IRTF design.

Conclusions

The work provides a framework for smart sensor systems. Rocket test is the motivating application, but the architectural approach is applicable to other applications such as manufacturing and process industries, and is applicable to security applications as well. The framework links distributed smart sensors into a coherent network using standardized interfaces and an expert system tool as the core. Among the improvements anticipated in overall system functions includes increased reliability and better measurement confidence.

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