only one "clean up" coding pass). For M bit planes, this subprocess involves a total number of ($3M - 2$) coding passes. An embedded bit stream is then generated for each coding block. Information on the reduction in distortion and the increase in the bit rate associated with each coding pass is collected. This information is then used in a rate-control procedure to determine the contribution of each coding block to the output compressed bit stream.

In tier-2 coding, the results of those coding passes for each coding block that have not been discarded are organized into an output compressed bit stream. With a carefully optimized implementation of a discrete wavelength transform, the embedded block coding tends to dominate the whole encoding time; consequently, prior JPEG 2000 encoding algorithms waste computational power and memory on those coding passes that are eventually discarded. This concludes the background information.

A complete description of JPEG encoding with perceptual distortion control would greatly exceed the space available for this article, making it necessary to summarize briefly: The multiresolution wavelet decomposition and the two-tier coding structure of JPEG 2000 are amenable to incorporation of perceptual distortion control. In the present approach, one strives to determine the number of coding passes needed for each coding block by use of a perceptual model of the human vision system. Then only that number of (and no more) coding passes need be made in the tier-1 encoding.

A basic idea of the use of the perceptual model of the human vision system is to hide the coding distortion beneath detection thresholds, typically by exploiting the masking properties of the human visual system and establishing detection thresholds of just-noticeable distortion and minimally noticeable distortion based on psychophysical experiments. Among the masking properties included in the model are luminance masking [also known as light adaptation (in which the detection threshold varies with background light intensity)] and contrast making (in which the visibility of an image component is affected by other image components). The model also incorporates a perceptual distortion metric that takes account of spatial and spectral summations of quantization errors.

Experimental data have confirmed the expectation that in addition to yielding consistent image quality, JPEG 2000 encoding with perceptual distortion control makes it possible to do so at bit rates lower than those of JPEG 2000 rate-based distortion-minimization encoding. The figure presents comparative plots of such data, showing that the bit rate for a given level of normalized perceptual distortion is lower for perceptual distortion control.

This work was done by Andrew B. Watson of Ames Research Center and Zhen Liu and Lina J. Karam of Arizona State University. Further information is contained in a TSP (see page 1).

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning rights for the commercial use of this invention should be addressed to the Ames Technology Partnerships Division at (650) 604-2954. Refer to ARC-15522-1.

Intelligent Integrated Health Management for a System of Systems

Intelligent elements exchange information and each determines its own condition.

Stennis Space Center, Mississippi

An intelligent integrated health management system (IIHMS) incorporates major improvements over prior such systems. The particular IIHMS is implemented for any system defined as a hierarchical distributed network of intelligent elements (HDNIE), comprising primarily: (1) an architecture (Figure 1), (2) intelligent elements, (3) a conceptual framework and taxonomy (Figure 2), and (4) and ontology that defines standards and protocols.

Some definitions of terms are prerequisite to a further brief description of this innovation:

- A system-of-systems (SoS) is an engineering system that comprises multiple subsystems (e.g., a system of multiple possibly interacting flow subsystems that include pumps, valves, tanks, ducts, sensors, and the like).
- "Intelligent" is used here in the sense of artificial intelligence. An intelligent element may be physical or virtual, it is network enabled, and it is able to manage data, information, and knowledge (DIaK) focused on determining its condition in the context of the entire SoS.
- As used here, "health" signifies the functionality and/or structural integrity of an engineering system, subsystem, or process (leading to determination of the health of components).
- "Process" can signify either a physical process in the usual sense of the word

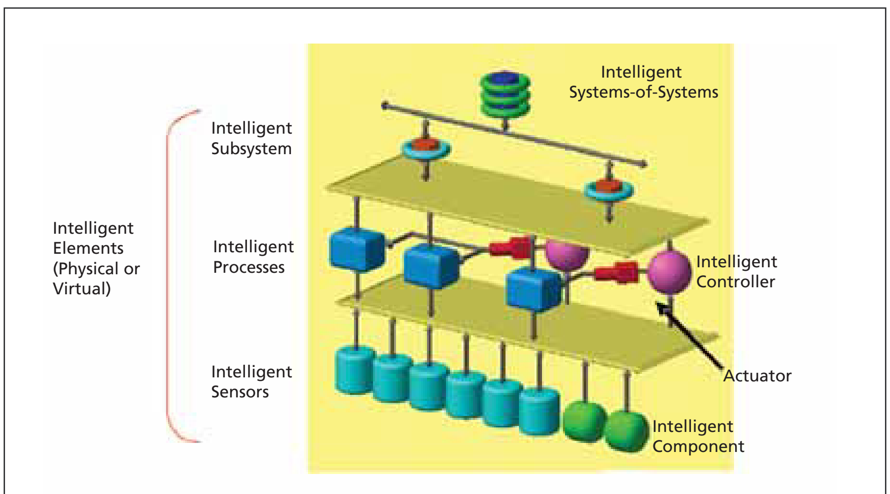

Figure 1. A **Hierarchical Network of Distributed Intelligent Elements** defines the architecture of the system described in the text.

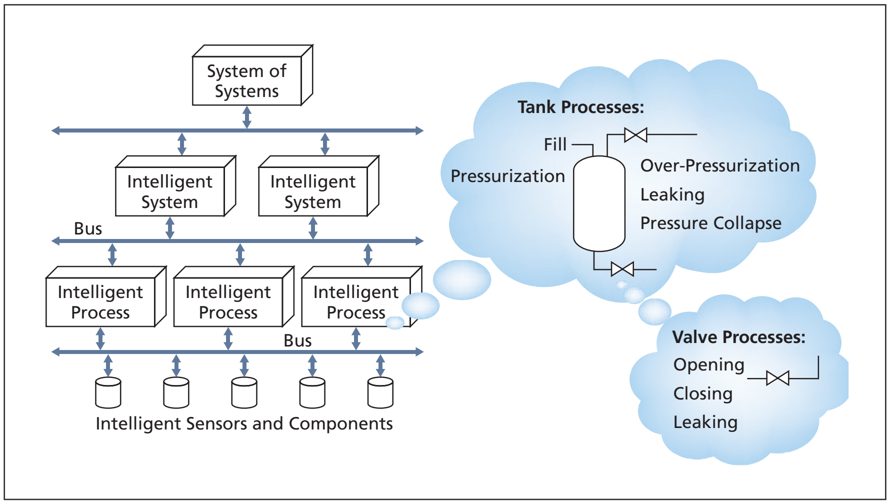

Figure 2. **Multiple Process Models** make possible an effective integrated approach.

or an element into which functionally related sensors are grouped.

- "Element" can signify a component (e.g., an actuator, a valve), a process, a controller, an actuator, a subsystem, or a system.
- The term Integrated System Health Management (ISHM) is used to describe 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.

A major novel aspect of the present development is the concept of intelligent integration. The purpose of intelligent integration, as defined and implemented in the present IIHMS, is to enable automated analysis of physical phenomena in imitation of human reasoning, including the use of qualitative methods. Intelligent integration is said to occur in a system in which all elements are intelligent and can acquire, maintain, and share knowledge and information.

In the HDNIE of the present IIHMS, an SoS is represented as being operationally organized in a hierarchical-distributed format. The elements of the SoS are considered to be intelligent in that they determine their own conditions within an integrated scheme that involves consideration of data, information, knowledge bases, and methods that reside in all elements of the system.

The conceptual framework of the HDNIE and the methodologies of implementing it enable the flow of information and knowledge among the elements so as to make possible the determination of the condition of each element. The necessary information and knowledge is made available to each affected element at the desired time, satisfying a need to prevent information overload while providing context-sensitive information at the proper level of detail.

Provision of high-quality data is a central goal in designing this or any IIHMS. In pursuit of this goal, functionally related sensors are logically assigned to groups denoted processes. An aggregate of processes is considered to form a system. Alternatively or in addition to what has been said thus far, the HDNIE of this IIHMS can be regarded as consisting of a framework containing object models that encapsulate all elements of the system, their individual and relational knowledge bases, generic methods and procedures based on models of the applicable physics, and communication processes (Figure 2). The framework enables implementation of a paradigm inspired by how expert operators monitor the health of systems with the help of (1) DIaK from various sources, (2) software tools that assist in rapid visualization of the condition of the system, (3) analytical software tools that assist in reasoning about the condition, (4) sharing of information via network communication hardware and software, and (5) software tools that aid in making decisions to remedy unacceptable conditions or improve performance.

This work was done by Fernando Figueroa of Stennis Space Center, John Schmalzel of Rowan University, and Harvey Smith of Jacobs Sverdrup.

Inquiries concerning rights for the commercial use of this invention should be addressed to the Intellectual Property Manager, Stennis Space Center, (228) 688-1929. Refer to SSC-00234.

Delay Banking for Managing Air Traffic

Delay credits could be expended to gain partial relief from flow restrictions.

Ames Research Center, Moffett Field, California

Delay banking has been invented to enhance air-traffic management in a way that would increase the degree of fairness in assigning arrival, departure, and en-route delays and trajectory deviations to aircraft impacted by congestion in the national airspace system. In delay banking, an aircraft operator (airline, military, general aviation, etc.) would be assigned a numerical credit when any of their flights are delayed because of an air-traffic flow restriction. The operator could subsequently bid against other operators competing for access to congested airspace to utilize part or all of its accumulated credit. Operators utilize credits to obtain higher priority for the same flight, or other flights operating at the same time, or later, in the same airspace, or elsewhere. Operators could also trade delay credits, according to market rules that would be determined by stakeholders in the national airspace system.

Delay banking would be administered by an independent third party who would use delay banking automation to continually monitor flights, allocate delay credits, maintain accounts of delay credits for participating airlines, mediate bidding and the consumption of credits of winning bidders, analyze potential transfers of credits within and between operators, implement accepted transfers, and ensure fair treatment of all participating operators.

A flow restriction can manifest itself in the form of a delay in assigned takeoff time, a reduction in assigned airspeed, a