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SENSWEB: A WIRELESS SELF-ORGANIZED COOPERATIVE SENSOR NETWORK TOPOLOGY

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Abstract: Honeywell has been developing an exciting new Web-based architecture called *SensWeb.* This totally new approach to information sharing and decision-making for vehicle health monitoring and condition-based maintenance applications consists of numerous (hundreds to thousands of) sensors. These low-cost sensors (i.e., polymer thick film) are highly redundant in nature and have some processing capability and memory capacity. Sensors can be configured to have individualized passive or active sensor webs to increase coverage and improve overall sensor network performance. The SensWeb architecture is logically organized into three layers of processing: the individual sensor, web clusters of sensor nodes, and collections of sensor web clusters.

Key Words: Distributed sensor architecture, Power Aware, self-organized sensor, sensor web, wireless sensors

Background: NASA and all DoD agencies currently employ "walk-around inspection" as a cornerstone for performing vehicle and asset health monitoring. This means that a hierarchy of inspections is required to ensure fleet readiness and guarantee that availability requirements are met. The DoD inspection schedule includes daily inspection, phased maintenance based on operating time, conditional inspection based on mission and location of the DoD assets, calendar-based inspection, and limited on-board vehicle monitoring.

Some of the key issues related to vehicle and asset health monitoring include:

- Key Damage/Failure Modes—Fatigue cracking due to thermomechanical cycling, impact damage and delamination, thermal overstress, thermal fatigue, or corrosion.
- Damage Assessment—Interpretation of damage in composites is challenging due to lack of adequate sensor coverage and sensor reliability.
- Harsh Environmental Exposure—The operating environment has a direct impact on sensor reliability, calibration, and operation.

Technical Approach: This section summarizes the key technical approach for SensWeb [1,2]. A quick summary is provided, including an overview of how SensWeb can offer the benefits of sensor array construction without adding significant weight or volume. SensWeb consists of numerous sensors (hundreds to thousands). These low-cost sensors (i.e., polymer thick film) are highly redundant in nature and have some processing capability and memory capacity. Sensors can be configured to have individualized passive or active sensor webs to increase coverage and improve overall sensor network performance. Figure 1 shows the SensWeb data flow hierarchy. The architecture is logically organized into three layers of processing: the individual sensor, web clusters of sensor nodes, and collections of sensor web clusters. Since a large amount of data is collectively generated by the sensor nodes, the information processing approach is that of progressively increasing the algorithmic complexity when progressing from the individual sensor to the sensor node cluster and, finally, among sensor node clusters. At the same time, the data content that is transmitted through the SensWeb layers is decreased due to local preprocessing performed at the sensor level. In this way, the sensor nodes can effectively reduce the data communication bandwidth and improve power management capabilities.

Low-Cost Polymer Sensors: Using polymer thick-film technology (PTF) and elastomer materials, Honeywell is developing a family of low-cost sensor-on-film technology capable of sensing temperature, moisture, vibration, structural impact, and strain quantities. These sensors conform to surface profiles (6 to 10 mils thick), adding little weight, and can be easily replicated to provide a deeply distributed and highly redundant sensor web architecture solution. The PTF approach is based on the novel idea of directly integrating sensory, control, and data processing electronics into the coating protectant system of interest (vehicle, asset, spaceborne structure, etc.). The polymer sensory system is proposed to conform to the shape of the surface into which it would be integrated, or in other words, to be "conformal," which means to "have the same shape or contour."

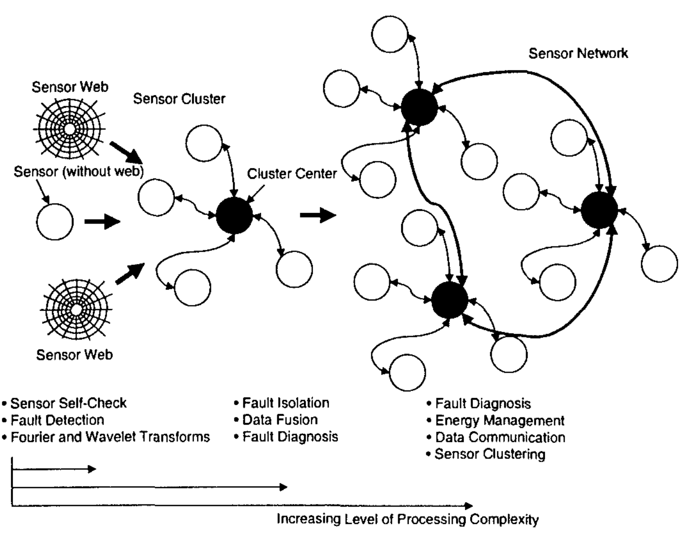

Figure 1. SensWeb Data Flow Diagram

Honeywell has been working under internal research funds for 2-1/2 years to develop conformal sensing, which integrates polymer films with PTF-based "built-in" sensory functions. The technical approach is based on the novel idea of using a polymer film as a flexible substrate, on the backside of which electrical interconnects, sensory functions, and data processing electronics would be directly integrated. The sensory functions are defined by incorporating polymer thick-film patterns on the film surface bonded to the surface of the test structure.

Figure 2 illustrates a concept for moisture/corrosion sensing as an edge seal detection scheme. The figure shows a film panel peeled back to reveal a set of PTF sensing elements located on the backside of the film. The polymer sensing elements are organized as a linear array to detect the integrity conditions of the structural panel edge seal. The linear array elements are shown in the detailed view of the figure and positioned near the edge of the panel to detect penetration of moisture and fluid ingress. Each array element is designed as a "built-in" sensory function to detect the presence of moisture ingress from the edge of the panel as a conductivity measurement. The array element is organized to sense moisture based on a unique polymer film circuit pattern, which is printed on the backside of the film using standard inkjet processing techniques.

Honeywell has performed additional internally funded development that demonstrates the feasibility of using PTF sensing to perform functions for impact force (i.e., barely visible impact damage, or BVID) and conformal antennas with the potential of also sensing airflow (i.e., air data), temperature, and vibration parameters.

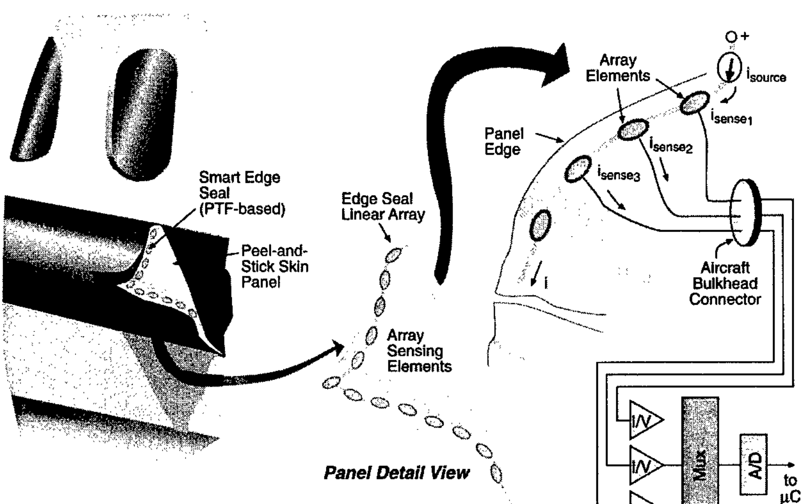

Figure 2. Smart Edge Seal Concept

A key benefit of the polymer sensor array is its multifunction sensing. The polymer circuit pattern implemented for moisture/corrosion sensing is also capable of sensing impact forces caused by maintenance-induced damage or operational servicing. To provide sensing for impact forces, the linear sensor array is configured with an additional semiconductor polymer layer, as shown in Figure 3. The design approach is set up to operate as a force-sensing resistor (FSR). An FSR operates on the principle of converting force applied via a structural impact event to an equivalent voltage output. As pressure is applied to the sensor pattern, individual pairs are shunted, causing a decrease in electrical resistance.

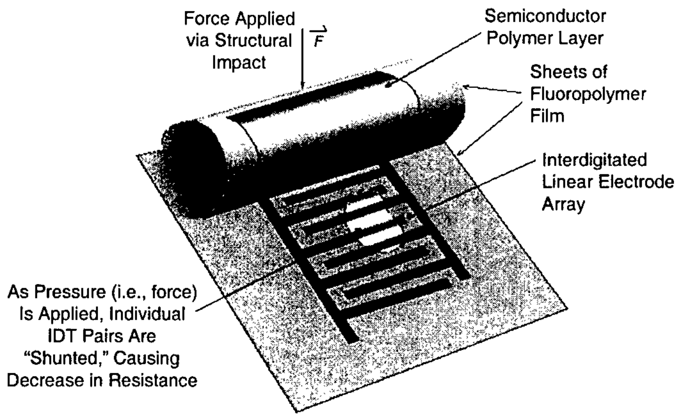

Figure 3. Force-Sensing Resistor (FSR)

Sensor Web Topology: An exciting area of research for asset monitoring applications currently being investigated by Honeywell is sensor web architecture topologies. The term "sensor web architecture" refers to the methodology by which sensor resources are allocated and physically organized in monitoring applications. A smart structure/vehicle element is illustrated in Figure 4. The figure highlights a conceptual view of several sensor webs distributed uniformly on the surface of the smart structure. Each sensor web would be implemented to sense structural parameters of interest, such as vibration or acoustic emission, when embedded into the structure or structurally bonded as a conforming polymer skin.

The advantages of having this kind of sensor distribution proposed in SensWeb are:

- Coverage of a large area by unifying the coverage areas of a multitude of individual sensors.
- Greater sensitivity to system faults by using all the available collective sensor information.

- The information resolution available is very broad—from raw data from single sensors to fault information about a region covered by a group of sensors to whole system information.
- The algorithms for fault detection, diagnosis, and isolation can be specialized at different locations. This allows for a more powerful system analysis methodology.
- Different sensors can be distributed as part of the common sensor network. Data fusion algorithms can process data from different sensor types, and more accurate fault diagnosis is possible.

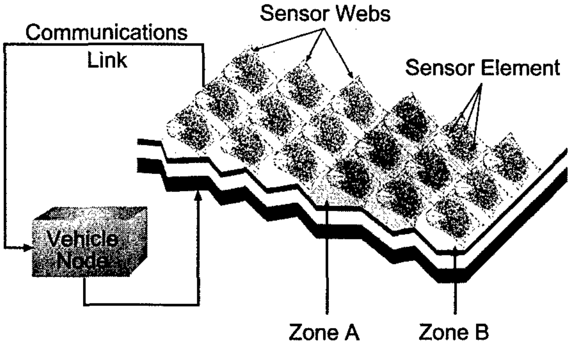

Figure 4. SensWeb Topology

A specific focus of Honeywell's recent research in sensor web technology is investigating alternative methods for constructing sensor layouts to provide optimal sensor coverage and performance. The unique construction pattern of a "spider web" offers several significant benefits to a potential user, including:

- Improved Sensor Coverage—The centralized hub web design implemented by a spider allows much-improved coverage. The typical "orb-style" design facilitates detection of a friend or food for the spider by using the web as a "sensor antenna," as the vibration signature transmitted via the web is detected as a unique signature. The same principle of operation could be applied for structural monitoring applications where a dedicated polymer sensor element could be located at the center or hub of a polymer-like sensor web to detect structural vibrations, achieving 100% coverage at minimum cost.
- Best Sensor Mapping—The radial design web structure provides an optimal method for mapping sensor resources on complex shaped surfaces.
- Power-Aware Wireless Communications—PTF sensors are envisioned to communicate and share data via seamless peer-to-peer communications. Bluetooth and related wireless network protocols will be implemented to provide key benefits of wiring weight savings, reduced sensor installation and maintenance costs, and

sensor placement optimization. Power-aware architecture techniques (i.e., clock gating, frequency scaling, power vs. performance constraints, sensor correlation, virtual sensing) will be incorporated to adaptively turn power on and off according to processing needs and minimize power to complete mission tasks. To accomplish this, power and energy will be treated as independent system-level variables to be optimized via real-time assessment.

Conclusions and Summary: The details of sensor web architecture design and polymer PTF sensors have been presented. The SensWeb architecture is logically organized into three layers of processing: the individual sensor, web clusters of sensor nodes, and collections of sensor web clusters.

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INDUSTRIAL CASE HISTORIES

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