Expandable sensor networks for Structural Health Monitoring

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Outline of Presentation

- Space needs
- SHM Background
- Expandable sensor networks
- Testing and results
- Summary
Motivation/Need

- Structural Health Monitoring (SHM) uses sensors integrated with a structure enabling continuous or periodic inspection of areas that are difficult to access.

- SHM systems using built-in sensors can be used to accurately monitor damage, reduce man hours for structural inspection and move towards predictive maintenance.

- However it is hard to apply SHM for large structures because of the following challenges:
  1. **SHM system** needs to be matured for use with complex large structures and sensor network needs to be optimized.
  2. **Sensors** need to be designed for **installation** with the large structures.
  3. **System** needs to have accuracy in **damage detection**, localization and quantification.

**Presentation focus:** Acellent will provide an overview of its expandable sensor network based SHM system that can meet these challenges.
Acellent’s complete SHM solution can be used for monitoring and detecting damages in any type of structures in platforms such as aircraft, spacecraft, rotorcraft and civil infrastructures.

**HOT SPOT MONITORING**

**CORROSION MONITORING**

**DYNAMIC STRAIN MONITORING**

**LARGE AREA MONITORING**

**IMPACT DETECTION AND MONITORING**
Acellent SMARTER SENSORS Technology

- Integrated sensor network
- Ease of installation using flexible thin film technology
- Uses a network of sensors – entire area can be monitored not just discrete points
Acellent SHM System Operational Modes

- An applied voltage causes piezoelectric material to expand and contract
- Conversely, deformation of the material generates a voltage

Any type of structural damage/anomaly can be detected

**Active Interrogation**
- Actuation Signal
- Detects Damage

**Passive Sensing**
- Sensor Data Received
- Monitors Impacts
SHM SYSTEM STANDARD FUNCTIONS AND CAPABILITIES

• DATA ACQUISITION
  – Data acquisition & Damage imaging
  – Data export & management

• SENSOR INTEGRITY
  – Sensor integrity check

• ENVIRONMENTAL COMPENSATION
  – Environmental compensation for data reliability

• DAMAGE DETECTION AND QUANTIFICATION
  – Level I: detection
  – Level II: location identification
  – Level III: damage size quantification (using optimized sensor layout or calibration)
  – Optional - Level IV: effect of damage on structural integrity (Prognostics)

• OPTIMIZED SYSTEM PERFORMANCE FOR APPLICATIONS. (Provides greater control over system set-up and usage)
Acellent’s SHM installed on U.S. Air Force Future Responsive Access to Space Technologies (FAST) Airframe & SHM Ground Experiment (AFGE) Program

**SHM focus:**

(1) TPS Impact  
(2) TPS Bolt Loosening  
(3) Tank Delamination

<table>
<thead>
<tr>
<th>Impact Energy, X (ft-lbf)</th>
<th>Characteristic</th>
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<tbody>
<tr>
<td>X &lt; 3.0</td>
<td>Light impact, system outputs green status</td>
</tr>
<tr>
<td>3.0 ≤ X &lt; 8.0</td>
<td>Medium impact, system outputs yellow status</td>
</tr>
<tr>
<td>X ≥ 8.0</td>
<td>Damage impact, system outputs red status</td>
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SMART Layer - Design and Manufacturing for Embedding in Automobile Parts

- Foam and graphite epoxy sandwich structure
- Integration using resin transfer molding

SMART Layer designed for complex composite sandwich part
SMART Layer manufactured and embedded inside the composite sandwich part

Actuator-sensor paths

Sensors

SMART Layer
Need for Technology Improvements

Current Technology is limited due to:

- Size of current sheets dictates the maximum length of a SMART Layer
- Techniques for jointing multiple layer to create longer layers have been developed but are labor intensive and introduce higher rigidity
- Adding multiple SMART layers to a structure leads to more connectors and cables which increase weight and system complexity

Solution:

- Design sensor networks that can be manufactured in a small form factor and then expanded to cover large areas
Potential Solution

Expandable Sensor Network: Expanding SMART Layer through an unfolding technique
Expanding the SMART Layer to cover large areas
Miniaturization of data acquisition electronics: Leveraging AFOSR STTR Phase I

Focus on development of Flexible hybrid devices based on Application Specific Integrated Circuits (ASICs)
Acellent has tested the expandable sensors on various types of potential habitat structures.

1. A composite filament wound bottle previously available from Acellent was used.
2. An aluminum orthogrid was obtained from NASA Langley courtesy of Dr. Min from NASA Glenn.
3. A composite wrapped aluminum bottle has been obtained from NASA MSFC.
4. Hand made flexible weave of Aramid bound with silicone epoxy was manufactured by Acellent.
Demonstration of Damage Detection

All four structures were tested using the sensor network in conjunction with Acellent’s Passive Impact detection system (IMGenie hardware, AIM software) and/or SHM Composite Active system (ScanGenie III hardware, SHM Composite software).

**IMGenie III hardware**

**AIM software showing location, force and time**

**ScanGenie III active hardware**

**SHM Composite software showing damage location, damage size and damage type (custom)**
Testing on Composite Bottle
Passive system setup on composite bottle

- Expandable sensor layer
- Connector
- Calibration hammer
- IM Genie

To the PC

15 pin D-sub male connector

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Video 1: Passive system Impact Detection Demonstration
Damage Detection on Composite Tank using active sensing

Demonstration of ultrasonic damage detection system using installed PZT network as a set of pitch-catch ultrasonic actuators to detect changes in the structure

Warning sign that the system has detected a defect
Sample waveform generated by ultrasonic system

Automated damage detection system which looks for damage and if it detects damage attempt to localize and estimate the damage size

Estimated location and size of damage.

Picture of structure with sensor network installed. Note the location of the damage simulator which is meant to simulate the existence of a structural defect for testing. It is the presence of this simulator that is detected and localized by the software GUI (to the right) to demonstrate the system capability

Display of changes in structure detected by system which are assumed to be damage
Impact Detection on Composite/Aluminum Tank
Composite/Aluminum Tank test setup

Smart Layer

IM Genie

Connector

To the PC
Composite Tank Impact

GUI Output

🌟 Actual Impact Location
🌱 Estimated Impact Location
Impact Detection on Flexible Material
Flexible Composite Manufacturing

Flexible material made from Aramid weave with a silicone binder and Smart Layer sensors embedded in the layup.

Result: Material maintains flexibility even with sensors embedded.
Video 2 showing impact detection on flexible material note how the location of the impact appears on the laptop screen after every impact
Multisensor Network Testing on Aluminum Isogrid
Orthogrid Multi-Sensor Layer Sensor Locations

6 PZT sensors

Accelerometer

Strain Gauges
Impact Detection Example 1

GUI Output

Impact Location on Structure

★ Actual Impact Location
обытие

 Estimated Impact Location
Video showing testing of strain gauge rosette using structure as cantilevered beam and applying dynamic and static loads to the end. Note how the white line on the displace jumps when the load is applied.

Left: Resulting output from strain gauges from test in above video

Right: Orientation of strain gauges in rosette mebedded in the layer.

Note that the 90 degree (flexural direction) has the highest response while the 0 degree has the lowest.
Video 4: Temperature Sensor Testing

Demonstration of the temperature sensor embedded in the layer by heating with heat gun and cooling with compressed air. Final results on the left with video of test on the right. Note how the laptop screen in the video plots the temperature changes as they occur.
Autonomous space structures that can sense their health, detect damage, and also monitor the environments like a human can revolutionize the space industry. The flexible stretchable/expandable sensor network is a major building block to creating SHM technologies of the future. They can provide the ability to distribute sensors, actuators, electronics, etc. all over space structures while adding almost negligible weight. Acellent has demonstrated the following capabilities:

- Ability to build expandable sensor networks to cover an area larger than the manufactured size
- Integration of its sensor networks with a variety of material including: Aluminum orthogrid, flexible soft goods, composite wrapped aluminum, and wound composite
- Integration of the following sensors types: PZT, strain gages, temperature sensors, accelerometers
- The ability to detection impacts on both hard materials and soft goods, and the ability to perform installed ultrasonics on hard materials
We would like to thank Dr. Curtis Banks from NASA MSFC for his guidance during the program and assistance in helping obtain the test structures.