Flat Surface Damage Detection System (FSDDDS)

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Background

- KSC has been working in self healing and damage detection technologies for more than 10 years. Knowledge leveraged from the development of wiring damage detection systems.
- KSC IRTD FY11 funded project for development of hardware and software; used internal ink-jet printing technology for printing conductive traces
- Successfully demonstrated as a stand alone technology during 2011 D-RATS under IRTD.
- AES funded software modification allowed for communication with HDU avionics crew display which was demonstrated remotely (KSC to JSC) during 2012 integration testing.
- Integrated FSDDS system and stand alone multi-panel systems (AES funded) were demonstrated remotely and at JSC, Mission Operations Test using Space Network Research Federation (SNRF) network in 2012.
- FY13, FSDDS multi-panel integration with JSC and SNRF network
- Technology can allow for integration with other complementary damage detection systems
- Full patent application filed in 2012
DSH Technology & Innovations
Flat Surface Damage Detection System (FSDDS)

• **Flat Surface Damage Detection**: The Flat Surface Damage Detection system (FSDDS) is a sensory system that is capable of detecting impact damages to surfaces utilizing a novel sensor system. This system will provide the ability to monitor the integrity of an inflatable habitat during in situ system health monitoring.

• The system consists of three main custom designed subsystems: the multi-layer sensing panel, the embedded monitoring system, and the graphical user interface (GUI).

• The GUI LABVIEW software uses a custom developed damage detection algorithm to determine the damage location based on the sequence of broken sensing lines. It estimates the damage size, the maximum depth, and plots the damage location on a graph.

• Successfully demonstrated as a stand alone technology during 2011 D-RATS.

• Software modification also allowed for communication with HDU avionics crew display which was demonstrated remotely (KSC to JSC) during 2012 integration testing.

• Integrated FSDDS system and stand alone multi-panel systems were demonstrated remotely and at JSC, Mission Operations Test using Space Network Research Federation (SNRF) network in 2012.

• FY13, FSDDS multi-panel integration with JSC and SNRF network

• Technology can allow for integration with other complementary damage detection systems

FSDDS sensory panels system at MOT 2012

FSDDS data on Crew Display v2.0

FSDDS data on crew display during remote integration testing 2012
Raw damage data is transmitted serially and converted to Ethernet utilizing a Power over Ethernet Black Box. Each POE Blackbox has a unique IP address and Bluetooth device that is paired with a Bluetooth device on a unique detection panel, allowing monitoring of specific detection panels. The integrated panel (Panel #1) was monitored using an iPad running the crew display application. The stand-alone panels (Panels #2 and #3) were monitored using a laptop running the GUI in the control center.

Block Diagram Pictorial Representation of the Communication Layout of the FSDDS Stand-Alone and Multi-panel Systems for FY12

NASA Kennedy Space Center 2
DSH Technology & Innovations
Flat Surface Damage Detection System (FSDDS) FY12-F13 Status

• **Flat Surface Damage Detection**: The Flat Surface Damage Detection system (FSDDS) is a sensory system that is capable of detecting impact damages to surfaces utilizing a novel sensor system. This system will provide the ability to monitor the integrity of an inflatable habitat during in situ system health monitoring.

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• Integrated FSDDS system and stand alone multi-panel systems were demonstrated remotely and at JSC, Mission Operations Test using Space Network Research Federation (SNRF) network in 2012 (pictures left).
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FSDDS DSH software interfaces

- "raw" damage data
- reduced damage data

Networks:
- Ethernet between FSDDS Damage Panel Black Box and DSH Operations Computer
- Ethernet between DSH Operations Computer and Crew Display
- Ethernet between Crew Display and Java Display

Software Interfaces:
- FSDDS algorithm
- n/w stream WRITE
- n/w stream READ
- HaTS API DLL

Developers:
- KSC develop
- JSC develop
- LV function

Panel Black Box

Crew Display

Java Display
FSDDS Operations Summary

• The operation of the damage detection system is based on the use of parallel **conductive traces placed on a firm or flexible surface**.

• Several detection layers can be implemented, where **alternate layers are arranged in an orthogonal direction with respect to adjacent layers**. The orthogonal arrangement allows for pinpointing the exact location of the damage to the surface under test. **Multiple detection layers allow for the calculation of the depth of the damage to the surface under test**.

• **Minimizes the use of active electronic components** to reduce the risk of incorrect operation due to radiation factors. The **FSDSS circuit uses only two active components: a microcontroller, and a serial port bidirectional driver/receiver**. Wireless communication.

• **Microcontroller is used to inject and monitor test signals to determine the integrity of the sensing lines**

• **The data is transmitted wirelessly to a central commuting system**

• **A GUI monitors and controls the system**.
FSDDS Detection Panel Design

Damage Detection Test Panel Assembly

Legend:
- Conductive Traces
- Adhesive
- Fabric
Damage Detection Panel Fabrication

Insulation side of laboratory (left) and commercially (right) printed circuitry

Fabric side of laboratory printed and assembled multi-layered system (left) and commercially (right) printed circuitry and laboratory assembled multi-layered system (right)

Close up of laboratory ink-jet printed circuitry (left)
Three Dimensional Damage Detection

Detected Damage Attributes

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<tr>
<th>Damage ID</th>
<th>Total Lines Broken</th>
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Damage Zones

- X-Y Coordinates Accurate (T)
- X-Y Coordinates
  - X: 5.08
  - Y: 5.2

- Defect Lines Found Near Zone
- Defects Found Near Zone: 4
- Estimated Damage Lines Width: 3
- Estimated Damage Lines Length: 3
- Damage Depth Layer: 2
- Estimated Area (Sq. Inches): 0.0144
- Estimated Width (Inches): 0.12
- Estimated Length (Inches): 0.12
- Damaged Lines / Zone: 463
- Broken Lines / Zone: 6
- Coordinate Depth Layer: 6
- Current Max Damage ID: 0
- Current Damaged Lines: 0
- Total Available Lines: 446
- Total Broken Lines: 226

Start Monitoring  Stop Monitoring

Length (Inches)  Damage Color Legend

- Monitoring (T)
- Status Data Received (T)
- Display Defect Lines (T)
- Top Layer
- 2nd Layer
- 3rd Layer
- Bottom Layer

Defects - Represented by DashDotDot Line Type
Unresolved Damage - Represented by Solid Line Type

Scanning Rate (Sec)
FSDDS DSH test configuration

- **FSDDS Damage Panel Black Box**
  - Ethernet connection
  - Uses **FSDDS algorithm** and **FSDDS “algorithm” .vi** for data processing

- **KSC computer**
  - Ethernet connection
  - Sends data to **n/w stream WRITE**

- **SNRF network**
  - Data transfer between KSC and JSC computers

- **JSC computer (+DSH)**
  - Ethernet connection
  - Uses **n/w stream READ**
  - Data is received by **FsDDs “RIU”.vi**

- **Java Display**
  - Connected to JSC computer

- **Crew Display**
  - Displays reduced damage data

- **“raw” damage data**
  - Sent from KSC computer to JSC computer

- **Reduced damage data**
  - Sent from JSC computer to Crew Display
### FSDDS data on Crew Display v1.0

**Legend:**
- PDU-A1
- PDU-B1
- PDU-B2
- PDU-F1
- PDU-H1
- PDU-H2

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FSDDS data on Crew Display v2.0
FSDDS Display Screen of Simultaneous (KSC and JSC) and Remote monitoring of multiple detection panels
FSDDS Labview Display of Multi-Panel Systems

Matrix Math Software upgrade being considered
Back up slides
Damage Detection and Self-Repair in Inflatable/Deployable Structures

Integrated sensors and self-repairing materials provide structural health management.

Inflatable/deployable structures are under consideration for applications as varied as expansion modules for the International Space Station to destinations for space tourism to habitats for the lunar surface. Monitoring and maintaining the integrity of the physical structure is critical, particularly since these structures rely on non-traditional engineering materials such as fabrics, foams, and elastomeric polymers to provide the primary protection for the human crew. The closely related prior concept of monitoring structural integrity by use of built-in or permanently attached sensors has been applied to structures made of such standard engineering materials as metals, alloys, and rigid composites. To effect monitoring of flexible structures comprised mainly of soft goods, however, it will be necessary to solve a different set of problems — especially those of integrating power and data-transfer cabling that can withstand, and not unduly interfere with, stowage and subsequent deployment of the structures. By incorporating capabilities for self-repair along with capabilities for structural health monitoring, successful implementation of these technologies would be a significant step toward semi-autonomous structures, which need little human intervention to maintain. This would not only increase the safety of these structures, but also reduce the inspection and maintenance costs associated with more conventional structures.

A series of proof-of-concept technology sensing and self-repair technologies have recently been developed and tested individually, for future integration into a full health management system for inflatable/deployable structures. With further development, these technologies could be applied individually or as part of an entire system, depending on the particular architecture of the structure or on the specific mission needs. The technologies include:

- Arrays of thin-film capacitive or inductive sensors, made of a flexible circuit material that can be integrated into an inflatable/deployable structure for use in detecting the location and extent of damage. Damage manifests itself as changes in inductance or capacitance in elements of the sensor array.
- Strain gauges made from thin films of amorphous silicon for monitoring the integrity of thin, flexible structures. To reduce the amount of wiring required, thin-film transistors are used to construct an addressable, matrixed array of sensors allowing selection and readout of specific sensors in the array.
- Wireless sensors and passive (no-power) radio-frequency identification sensor tags to provide additional sensing capabilities such as strain sensing, temperature sensing, and impact or leak detection, without the need for data and power cables.
- Self-repairing elastomeric materials (such as those used to construct the bladder of a habitat), which incorporate microcapsules filled with a monomer resin and a small amount of a polymerization catalyst. Upon damage to the material, some of the capsules burst and release the monomer, becoming polymerized after making contact with the embedded catalyst and thus effecting repair of the damage.
- Sensory and self-repair features will eventually be combined into the structure to effect a unified structural health maintenance system. Sensors will alert humans to initial damage and will monitor the self-repair process, to indicate whether there is a need for human intervention for inspection and/or repair.

This work was done by Erik Brandon of Caltech, George Studor of NASA Johnson Space Center, David Banks and Mark Curry of Boeing Phantom Works, Robert Broccato of Sandia National Laboratories, Tom Jackson of Penn State University, Kevin Champagne of Invocon, Stan Woodard of NASA Langley Research Center, and Nancy Sottos of the University of Illinois at Urbana-Champaign for NASA’s Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov, NPO-44519